FRICTION BETWEEN STEEL SPRINGS USED IN WAUGH DRAFT GEAR

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ARMOUR INSTITUTE OF TECHNOLOGY

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A THESIS

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ARMOUR INSTITUTE OF TECHNOLOGY

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FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

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FRICTION BETWEEN FLAT STEEL SPRINGS AS USED IN THE WAUGH DRAFT GEAR

A THESIS

PRESENTED BY

E. ENDICOTT BOLTE
WILLIAM E. THOMAS

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

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HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

MECHANICAL ENGINEERING

1910

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PREFACE.

Friction is the mechanical resistance which opposes the motion of one body upon another providing there are no forces applied to resist this motion. Friction between dry surfaces is divided into two classes, friction of rest and friction of motion. The quantity of friction between to or more surfaces depends upon the following: the kind of material used, the nature and area of the surfaces, the load applied, and the speed with which the load is applied.

When a series of flat steel springs are caused to bend upon each other, each spring taking the same curvature as the preceding one, friction is generated between the surfaces. These springs are supported at their ends and caused to bend by a load varying from one centrally applied at the start to an uniformly distributed load at the end of a certain deflection, well within the elastic limit. The friction thus developed opposed the deflection and also retards the recoil of the springs. The resistance of these springs to bending and that of the friction between them constitute the principles used in the Waugh Draft Gear which is taken as a basis for this thesis.

FRICTION BETWEEN FLAT STEEL SPRINGS AS USED IN THE WAUGH DRAFT GEAR.

Draft gears are used on all steam and electric cars to cushion the blows caused by the impact of the cars when thrown together and also to eliminate the jolting caused by the starting and stopping of these cars. These gears are placed directly behind the couplers and between the sills of the car, the blow being transmitted to the gear by means of the draw bar. The most efficient gear is that one which will cushion all blows within its capacity; which has just enough recoil to kick the cars apart so that the gear will be in its original position and ready to receive the second shock; and which will stand the most wear and tear without breaking down. A great variety of these gears are made, using many different principles. The two principles most used are the resistance offered by springs and that offered by friction. The Waugh draft gear makes use of both of these. This consists of groups of straight steel plates which under compression are curved over oval surfaces by movable blocks separating each pair of groups at their ends.

In curving these plates offer a resistance to bending, and the increasing curvature of the plates under compression is attended by a frictional adhesion of their individual surfaces, which adds to their cushion capacity and retards their return to the straight position, thus reducing the violence of the recoil.

There are three ways of testing these gears. The first and best method is to test the gear under the same conditions as are found in actual practice, i.e. on the cars. The second is on a standard master car builders drop test machine, which consists of a frame work operating a drop of forty feet, the weight being sixteen hundred and forty pounds and arranged substantially like a pile driver. The machine may rest upon either a solid foundation or upon heavy coil springs, the latter giving a test under conditions nearer to the actual than the former. In both the first and second methods an absorption dynamometer may be used to register the blow. The third method is to test the gear upon a slow compression machine. Of course the first is the real test but of the other two the results will depend upon the kind of a gear used.

Some claim that the static machine acts under conditions nearer to the actual than the drop test, while others claim the reverse is true. When two cars are thrown together, the car which receives the blow moves thus making the time during which the blow acts longer than on the drop test machine, even if coils are used to mount it. The action of the static machine is much slower than either of these and in gears which make use of friction better results will be obtained than those found in dynamometer car test. But as this thesis is not on the efficiency of the Waugh draft gear and is on the friction between the flat steel springs used, a Reihlé' testing machine can be used to a better advantage than a drop test machine.

Two static machines have been used in making these tests, both Reihlé', one of 60,000# and the other of 200,000# capacity. In the first test a gear was set up without the frame work and driven solid, loads and deflections being taken both in the compression and the release. The gear as set up consisted of the following, the order of their position being taken from the bottom up to the top. The gear of course was set on end.

First a half oval was placed on the bed of the machine, the curved side being up and the flat side down. This is made of cast iron and was of the following dimensions:

Thickness at maximum curvature (center) = .79".
Thickness at end of oval (smallest curvature) = .17".
Breadth - = 6".
Length - = 11.5".

On top of this half oval were placed twelve plates of rolled spring steel, oil tempered so that only a certain set will be taken for a certain given deflection. The dimensions of these plates are as follows:

Thickness - .25"
Breadth - 6"
Length - 11.865"
Thickness of twelve plates - - - - - - - - - - 3.14".

Each of these plates have been tested out at the shops and therefore have a little set so that the twelve plates do not set closely together. This accounts for the extra fourteen hundredths of an inch in the thickness of the twelve plates. These plates are made to bend on and take the shape of the half oval. On top of these plates a separating block was placed.

This consists of a plate about 1/4" x 5" x 8" on the ends of which are cast lugs, 1-1/4" thick at the outer edge, having a flat space of 1/4" wide, one on each side and then curving down to the separating plate. The total length is about 11-3/4". These lugs are used as the supports for the ends of the plates and the separating plate connecting the two lugs prevents travel over a certain distance, on one side the maximum travel being = .53 and on the other = .52". Next in position is another group of twelve plates, having the same dimensions as the first group. On this second group of plates is placed a full oval, having the same curvature on both sides as that on the one side of the half oval. The dimensions of the full oval are as follows:

Thickness at the center - - - - - - - - - - 1.54".
Thickness at the ends - - - - - - - - - - - .15".
Length - - - - - - - - - - - - - - - - -11.50".
Breadth -- - - - - - - - - - - - - - - - - 6".

A group of eight plates of the same size as in the preceding groups is placed upon this full oval and then another separating block, the possible travel on each side being = .54" and .5" respectively.

Next in order came another group of plates and then a half oval having the same dimensions as the other. A round compression block about 8" in diameter was fastenend to the draw head of the machine and used as a means of applying the load. A clamp and stand were used to hold a scale, graduated to hundredths of an inch, parallel to the side of the draw head. A mark on this was used as a reference point and the reading taken, the difference in the readings being the travel of the gear. The maximum possible travel, not taking into account the setting together of the plates, is the sum of the distances .53",.52",.54" and .5", and is equal to 2.09". Readings could not be read any closer than one hundredth of an inch and when the capacity of the machine was reached the gear was solid to all appearances. The fact that after taking the gear to pieces worn places were found on each side of the plates in the separating shows that the gear was driven solid.

The blue print labeled "test No. 1." shows these results plotted, using the travel of the gear in inches as abscissas and the load in pounds as ordinates. A very soft cushion is obtained up to 60,000#, when the

load increases very rapidly for a very small deflection. The gear was solid at 205,000#, the capacity of the machine. When fully compressed, each group of plates has taken the full curvature of its oval bearing throughout its length and breadth. This brings the opposing groups in contact at ends and middle through the separators, thus constituting a solid mass of metal which fills the space between the sills of the car, and, as the strain is equally distributed, there can be no buckling of the follower plates, and hence no spreading of the sills. The release is very fast and follows almost a vertical line down to about 60,000#, when the travel is very fast for small loads. This release is probably caused by the frictional adhesion of the plates, as no travel is noticable until a very large load has been removed. The load drops so very rapidly that is is very hard to get many points in the release line until the travel increases very rapidly. A set of .45" was found in the four groups of plates and is due to the fact that the plates were softer than they ought to be. A set such as this, although a little large, would be all right providing that they would not set any more. If such a thing happened it would be a very weak point in the

gear because the travel would be constantly lessening and the nearer the travel is to being constant the better the gear. The readings were taken as follows: Two men ran the tests, one reading the travel of the gear and the other running the machine. The load reading was set for a given amount and the second the arm started to go up the operator called out and the travel of the gear read. In doing it this way the travel reading was taken at the same time as the machine was balanced and the load reading taken. In so doing a minimum error was introduced into the readings. The very slight increase in travel near the end brings up the question as to whether the gear is practically solid or not. If that small travel came first then the gear would be practically solid, but as it comes at the end of the travel the result is different. It is much the same as the case of an elevator, which, after dropping a couple of floors comes to a stop. A passenger feels no sudden shock. In actual use when one car is thrown against a second car, the gear cushions a greater part of the blow and then both cars begin to move. The result is that if there is any of the blow transmitted to the frame of the car when the car gear is nearly solid, the car is moving at that time and no harm is done.

Any way the combination of a slight travel of the gear and a little movement of the car would be the same as if the gear cushioned the full blow. It has previously been stated that the maximum possible travel was 2.09" while in this test a total travel of 2.57" was registered. This .48" is accounted for by the fact that the plates set together and cause a gripping action, giving a release such as is shown in the curve. The plates were not perfectly flat at the beginning of the run so the 2.09" is probably a little large. On a largemachine such as the one used it is very hard to get results within one or two hundred pounds and that means quite a little deflection, up in hundredths, so that our final reading of the deflectometer at the end of release is not always exact with a few hundredths.

The tests up to and including No. 6 were run on the same make up of the gear and the results are very constant, the general shape of the curve being the same and the load required to drive the gear solid nearly constant. About the only difference being in the total travel and the set as shown by the deflectometer. The plates set a little each time as shown by the deflectometer and also in the measurements

taken after the gear was taken apart. The travel is less every time due to this set. This set does not affect the final load very much because, as is shown on the curve, a small change in the deflection shows only a very slight change in the load. The area of the curve is affected by the amount of set taken. The more set that is taken, the greater the area. In a gear of this sort the area has little to do with its efficiency. If the efficiency of the gear depends upon the area or the amount of work done by the gear then the efficiency of this gear is very low. In test 7 the number of plates in each group was changed so that instead of having two groups of twelve plates and two groups of eight plates, there were four groups of ten plates each. As far as the curve shows the results were not changed. The travel increased. The plates in the bottom sets have more set than the top ones, so that when two plates were taken off of each of the two bottom groups and placed on the top two groups more travel was shown.

A separating block was then taken and one plate put on top of it. A half oval was then placed on this and the whole thing placed on a couple of flat blocks so that a deflectometer could be used to measure the deflection.

The plate was curved until it touched the separating plate and the load and deflection taken every few thousand pounds. In the same way two, three, and four plates were taken. When the fourth was run, the half oval cracked showing that the plates had deflected beyond the curvature of the oval. On examination it was found that the separating block had been deflecting so that the results had to be thrown away.

One side of a separating block was then planed off so that it would rest flat on the bed of the machine and there would be no chance for it to bend. One plate and a half oval were then placed on the separating block and were in turn placed upon a couple of blocks, as before, so that a deflectometer could be used. The plate was then curved until a piece of paper could just be pulled out from between the plate and the separating plate. The load and deflection were taken for every few thousand pounds for both release and compression. A load of 3,500# was required to deflect the plate .368". A test on two plates was then made, and for three and four. These results have been plotted on one sheet using the same coordinates as in the other curves.

The curve for the third plate was not plotted because of the irregularity of the points. Something, probably the deflectometer slipped and caused the results to be changed. A new set was then taken and starting with five plates tests were made on groups up to and including fifteen. These last tests have been plotted on one sheet. The area and load both increase as each plate is added. The plates were driven the same distance each time, the piece of paper being used, but this is not shown by the deflectometer readings. A slight load was put on the plates each time and the deflectometer set at zero. The plates set a little each time so that the travel grew less as the number of plates increased. Since the plates were driven the same distance each time and the resistance of one plate was 3,500#, the resistance of the plates themselves can be found by multiplying the resistance offered by one plate by the number of plates used. The difference between the load as actually found and the resistance of the plates themselves is the friction between them. The results show that up to five plates there is little or no friction between them, but as their number, and therefore the load, increases the friction increases greatly.

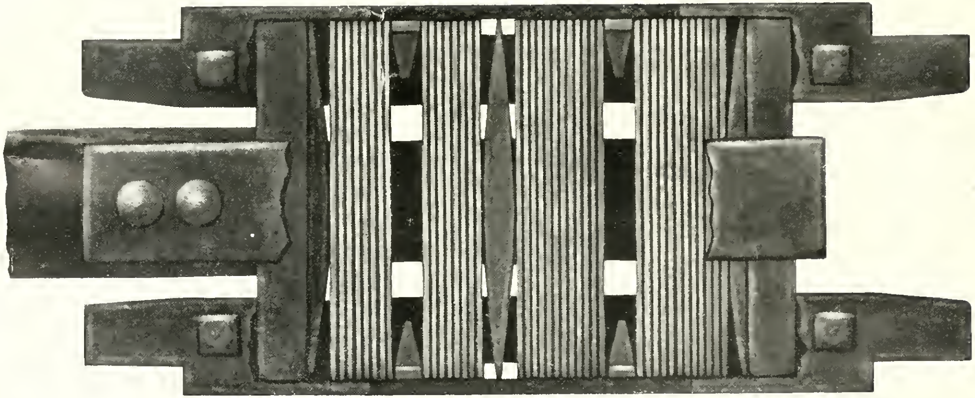
This is shown in the friction curve which is plotted using the friction as ordinates and the number of plates as abscissas.

Two groups of eight plates each were then taken, having a separating block in between and a half oval above and one below. This was driven solid and the load found to be 45,000#. The load for deflecting one group of eight plates was found to be 50,000#. This shows that one group of plates does nearly all the work. Two groups were set up in the same way and driven solid. The load required to do this was 190,000# which is practically the same as that needed to deflect two groups of fifteen. This again verifies that statement made above that one group of plates does nearly all the work, the other groups being used to give the travel required.

Two knife edges were then set 11-1/4" apart and fifteen plates set upon them. A deflectometer was placed so that the deflection could be measured, the screw being placed under the point of greatest curvature, near the outer edge of the plates. A load was then applied across the center of the plates by means of a knife edge and they were then deflected .5", more than they have been deflected in any other test.

This was done to see if the final travel had much to do with the friction. Readings of the deflectometer were taken every five thousand pounds both up and down and a curve plotted. The compression curve is convex and not concave as in the other tests. This has the general shape of the curve for steel. In the other tests the way the load was applied varied from centrally applied to uniformly applied at the full curvature. Evidently it is the method of applying the load that causes the friction between the plates. In the curve with a centrally applied load the release curve does not take the same shape as in the other tests. Immediately the load was taken off the gear began to release and it was very rapid too. In the other cases the release was very slow and much of the load was removed before any travel was noticed. This shows that it is caused by the peculiar method in which the load is applied.

William E. Thomas.



This illustration shows a plan view of wood sill application of the Waugh Draft Gear, with section of yoke and lug castings cut away, showing arrangement of groups of plates, ovals and blocks

(Over)

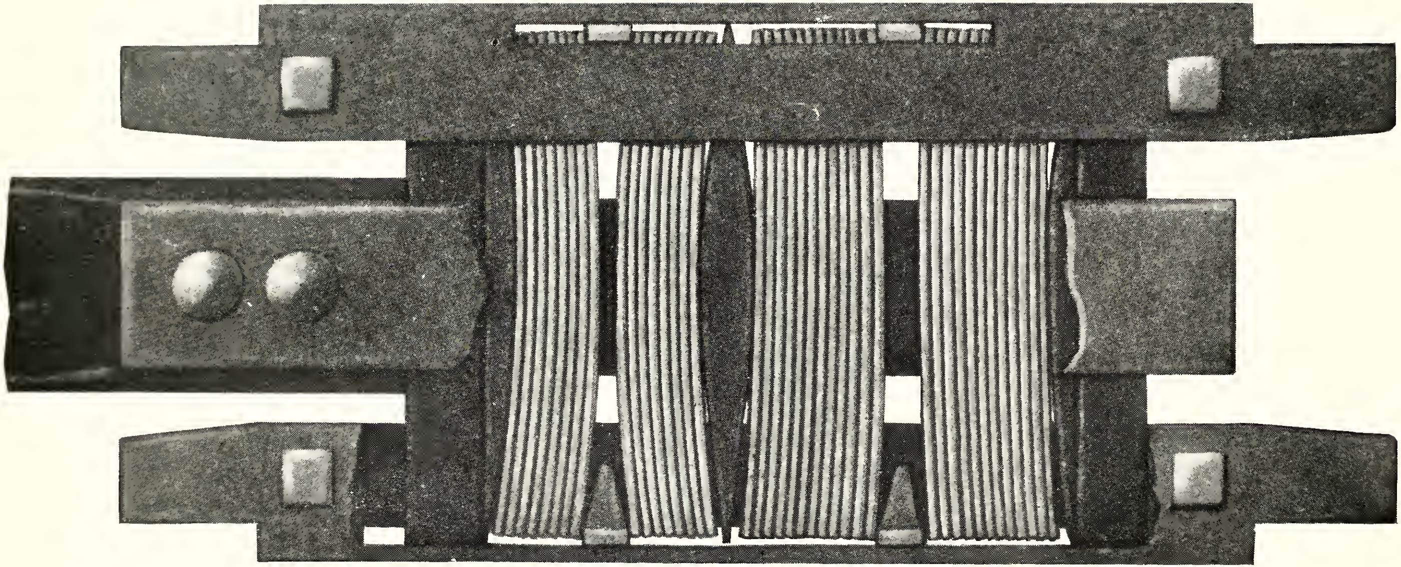


Illustration of the Waugh Draft Gear with the plates under one inch compression, giving a cushion of approximately 30,000 pounds

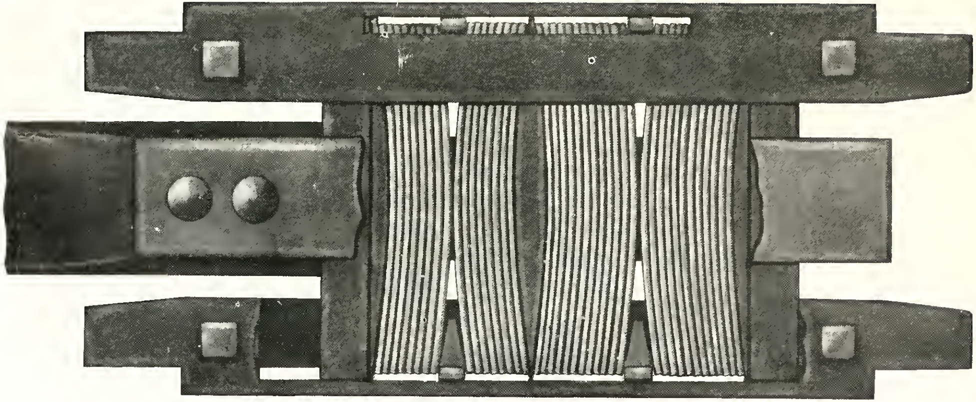


Illustration of the Waugh Draft Gear under full compression, showing operating parts closed at ends and middle. The draw bar travel is two and one-eighth inches, with a cushion capacity of 300,000 pounds

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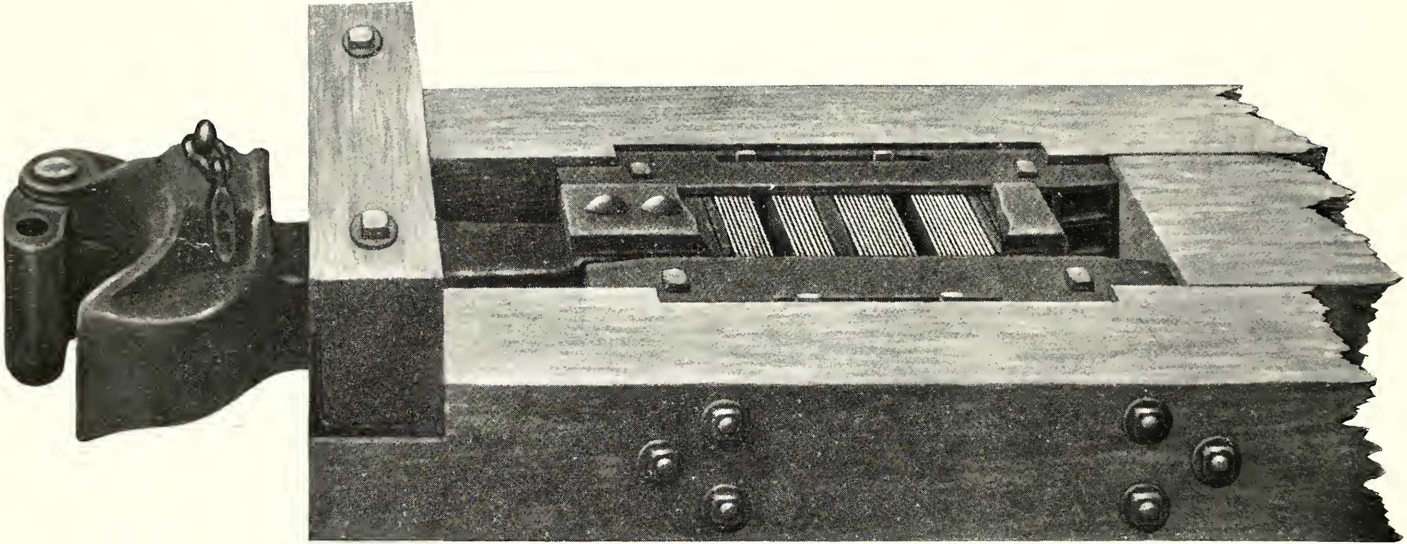
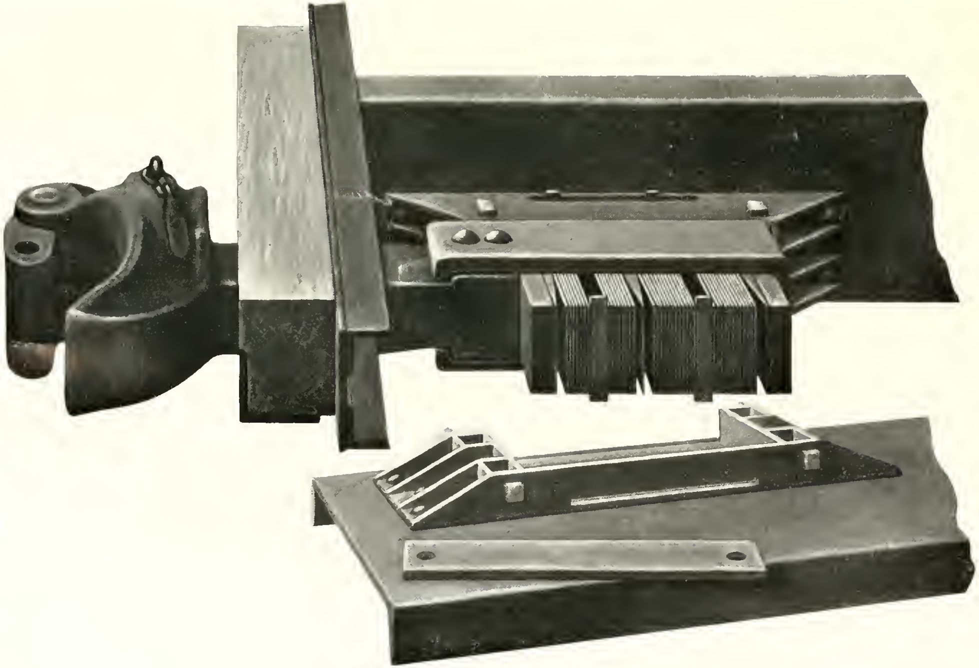


Waugh Draft Gear as applied to wood draft sills



Waugh Draft Gear as applied to steel sills

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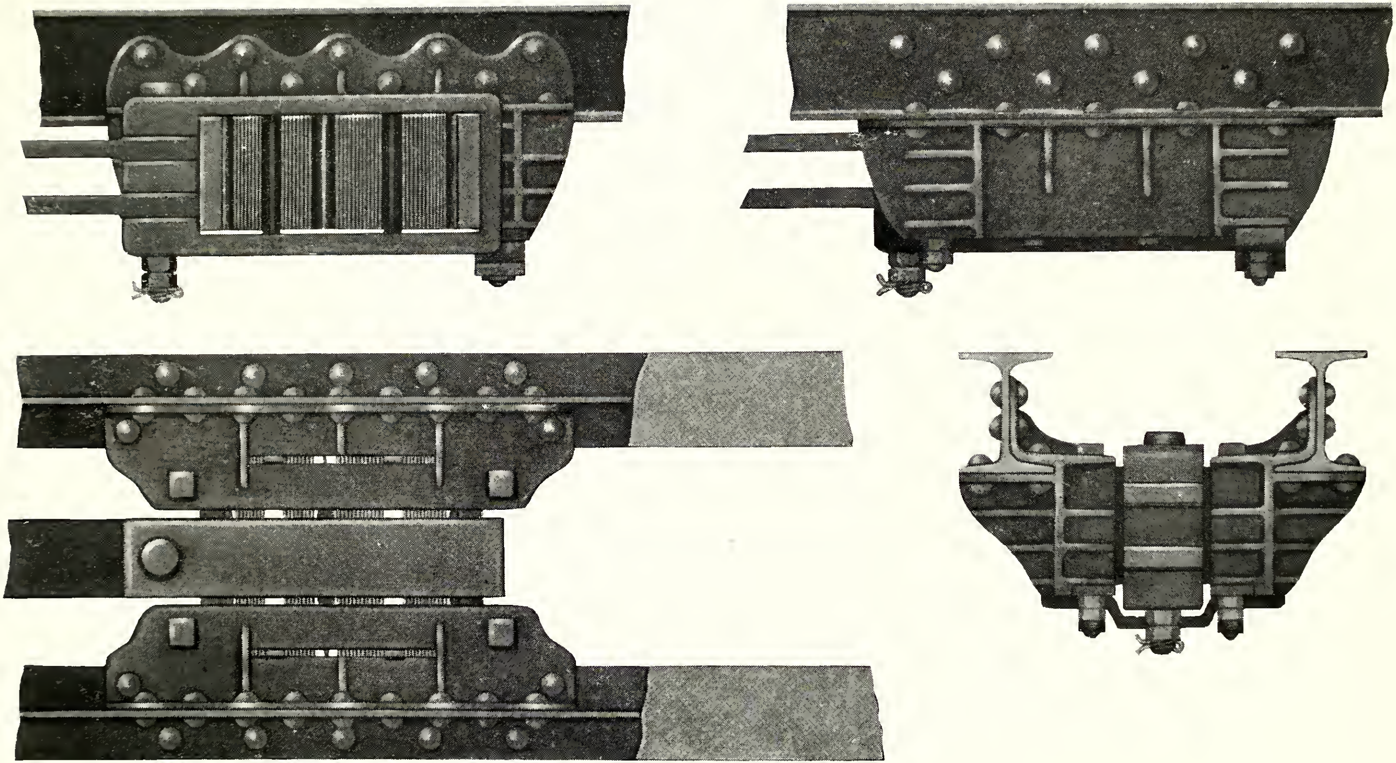


Waugh Draft Gear as applied to passenger cars equipped with the standard steel platform. Cushion capacity, 200,000 pounds

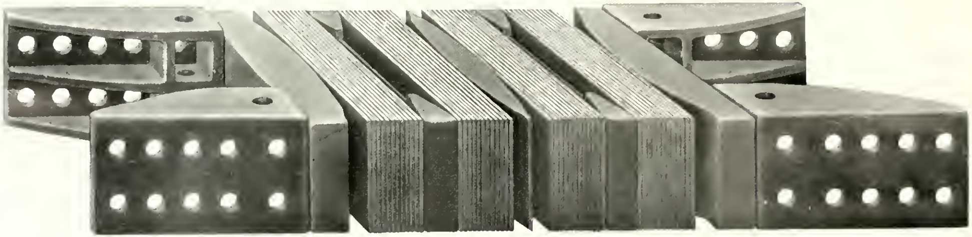


Illustration of the Waugh Draft Gear, designed to furnish about 500,000 pounds of cushion with blocks and ovals to admit three-inch travel of draw bar

(Over)

This Gear consists, per car, of:

4 cheek castings, which are attached to the sills.

8 groups of straight spring steel plates, varying in length and number to meet requirements as to cushion capacity, spread of sills and travel of draw bar.

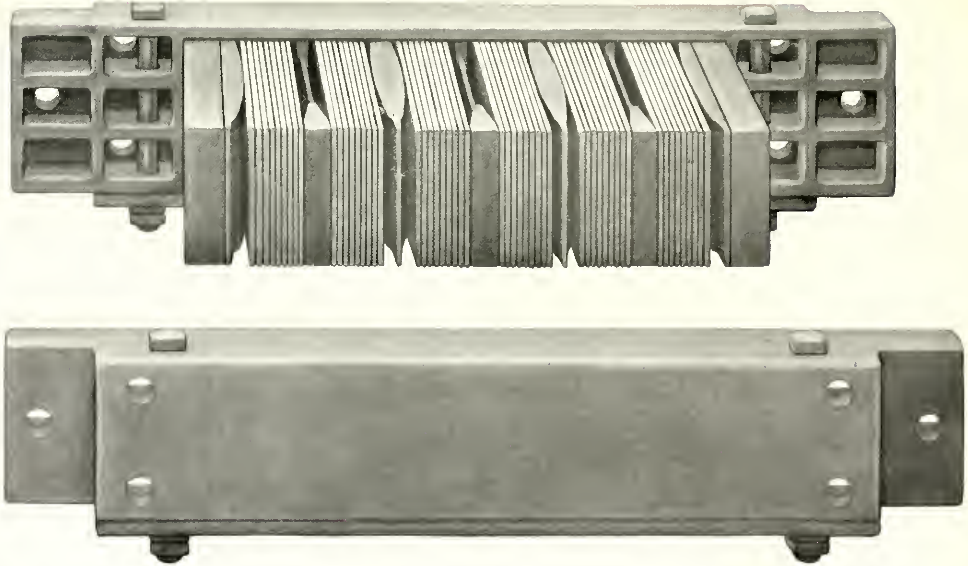
4 half ovals.

2 full ovals.

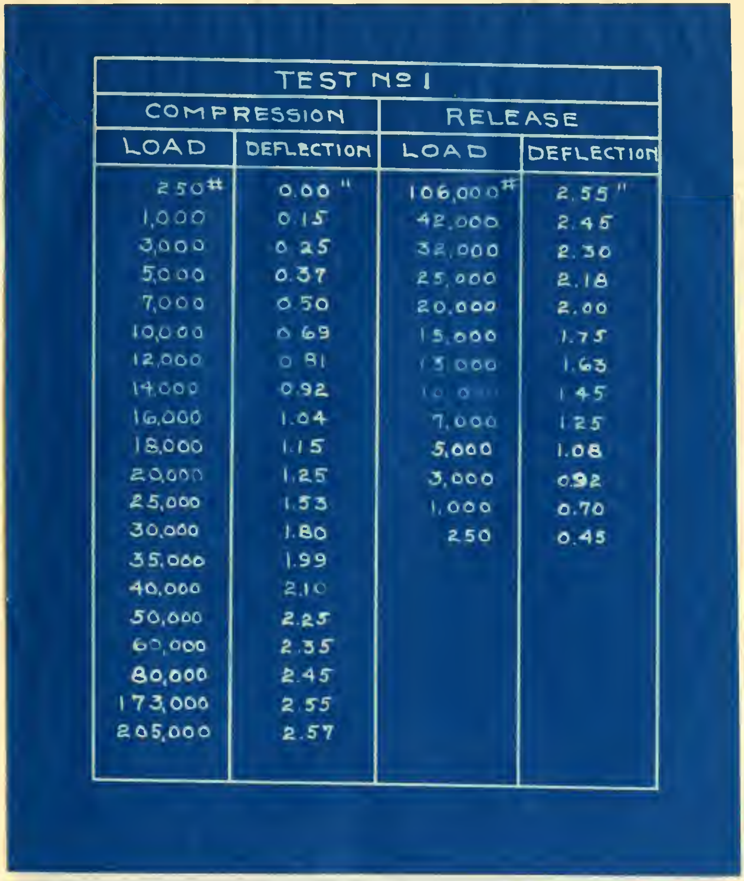
4 separators.

4 stiff follower plates.

4 carrier straps.

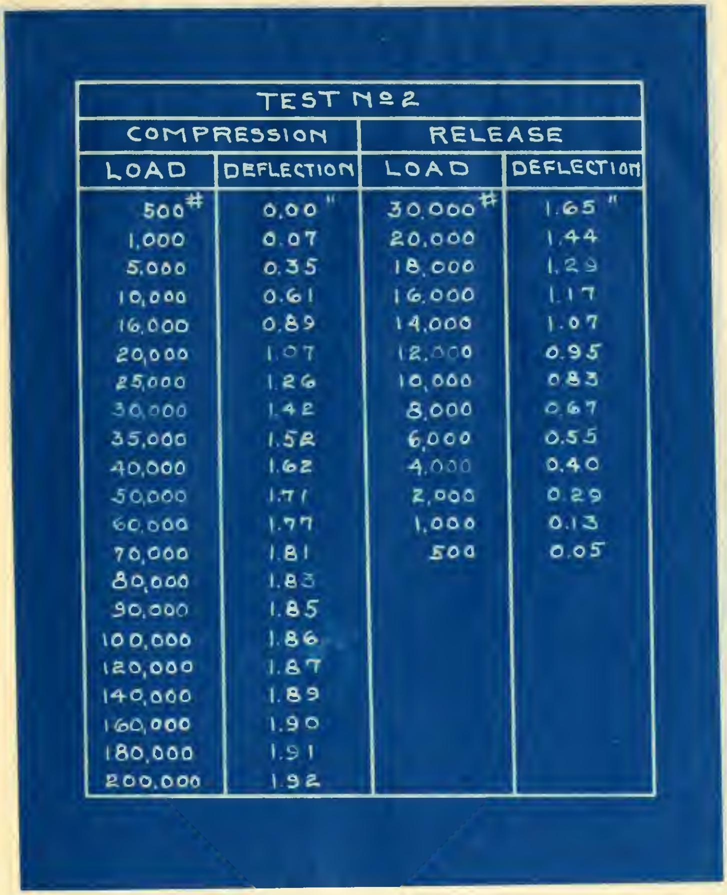


The Waugh Draft Gear as applied to wood sills on locomotive tenders



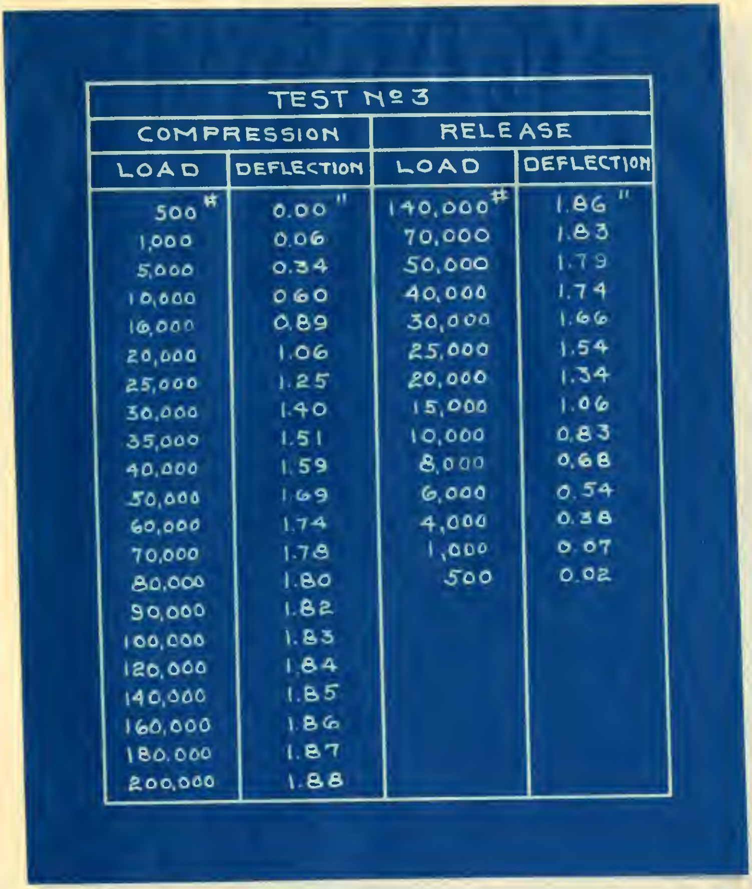
TEST Nº 1

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
250#	0.00"	106,000#	2.55"
1,000	0.15	42,000	2.45
3,000	0.25	32,000	2.30
5,000	0.37	25,000	2.18
7,000	0.50	20,000	2.00
10,000	0.69	15,000	1.75
12,000	0.81	13,000	1.63
14,000	0.92	10,000	1.45
16,000	1.04	7,000	1.25
18,000	1.15	5,000	1.08
20,000	1.25	3,000	0.92
25,000	1.53	1,000	0.70
30,000	1.80	250	0.45
35,000	1.99		
40,000	2.10		
50,000	2.25		
60,000	2.35		
80,000	2.45		
173,000	2.55		
205,000	2.57		



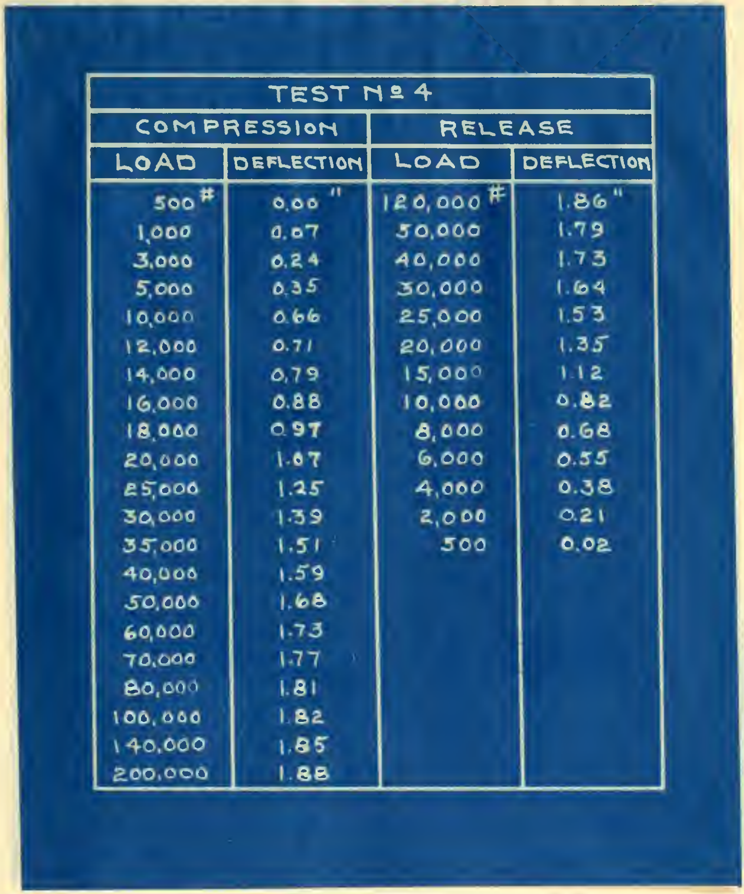
TEST Nº 2

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500#	0.00"	30,000#	1.65"
1,000	0.07	20,000	1.44
5,000	0.35	18,000	1.29
10,000	0.61	16,000	1.17
16,000	0.89	14,000	1.07
20,000	1.07	12,000	0.95
25,000	1.26	10,000	0.83
30,000	1.42	8,000	0.67
35,000	1.52	6,000	0.55
40,000	1.62	4,000	0.40
50,000	1.71	2,000	0.29
60,000	1.77	1,000	0.13
70,000	1.81	500	0.05
80,000	1.83		
90,000	1.85		
100,000	1.86		
120,000	1.87		
140,000	1.89		
160,000	1.90		
180,000	1.91		
200,000	1.92		

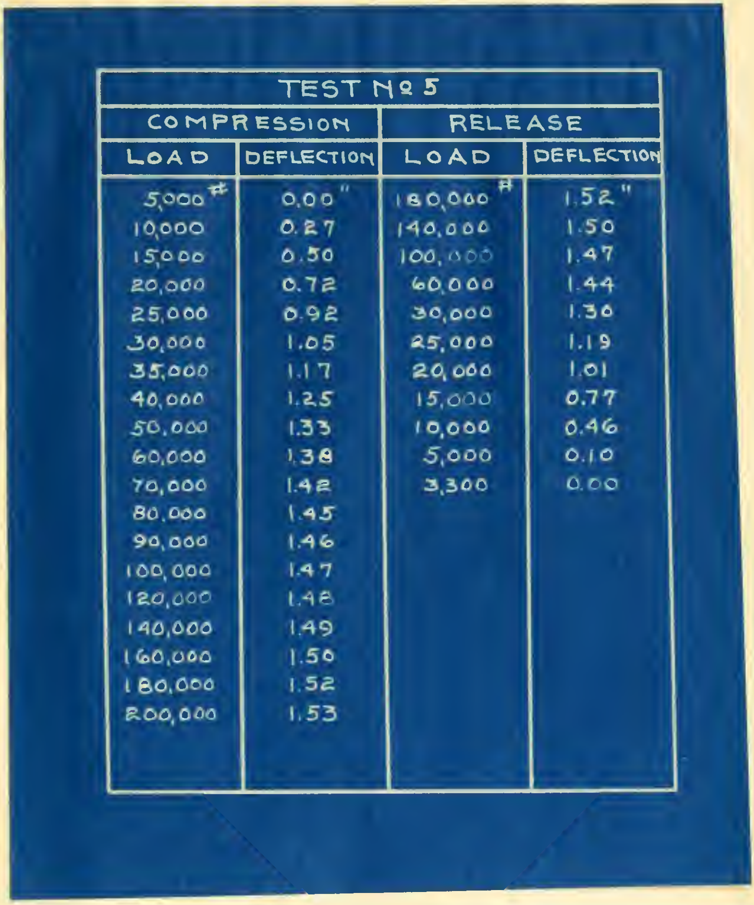


TEST № 3

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500 #	0.00 "	140,000 #	1.86 "
1,000	0.06	70,000	1.83
5,000	0.34	50,000	1.79
10,000	060	40,000	1.74
16,000	0.89	30,000	1.66
20,000	1.06	25,000	1.54
25,000	1.25	20,000	1.34
30,000	1.40	15,000	1.06
35,000	1.51	10,000	0,83
40,000	1.59	8,000	0,68
50,000	1.69	6,000	0.54
60,000	1.74	4,000	0.38
70,000	1.78	1,000	0.07
80,000	1.80	500	0.02
90,000	1.82		
100,000	1.83		
120,000	1.84		
140,000	1.85		
160,000	1.86		
180.000	1.87		
200,000	1.88		

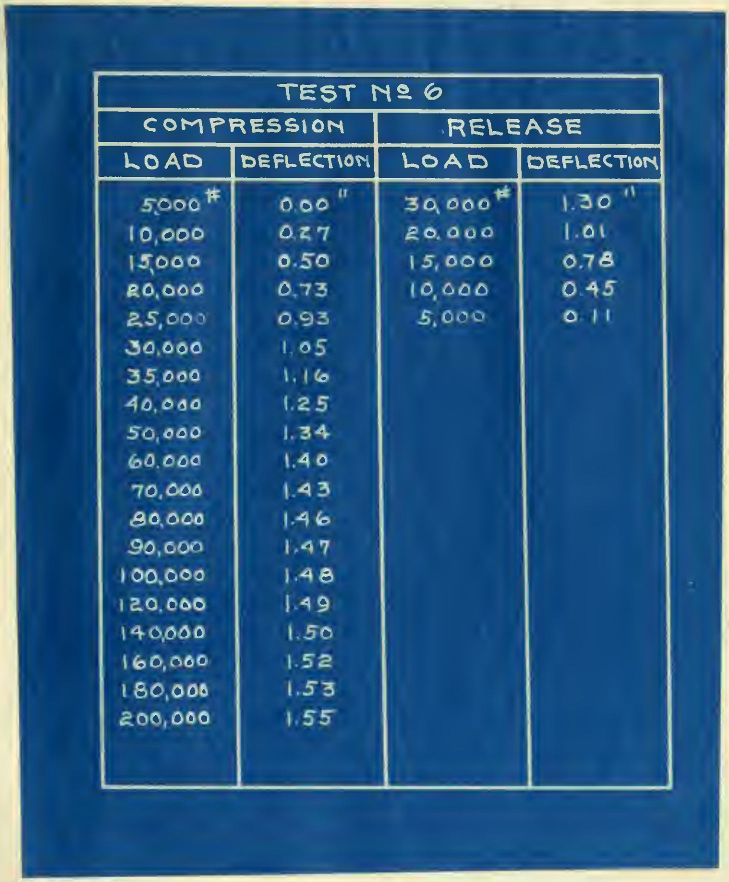


TEST Nº 4			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500#	0.00"	120,000#	1.86"
1,000	0.07	50,000	1.79
3,000	0.24	40,000	1.73
5,000	0.35	30,000	1.64
10,000	0.66	25,000	1.53
12,000	0.71	20,000	1.35
14,000	0.79	15,000	1.12
16,000	0.88	10,000	0.82
18,000	0.97	8,000	0.68
20,000	1.07	6,000	0.55
25,000	1.25	4,000	0.38
30,000	1.39	2,000	0.21
35,000	1.51	500	0.02
40,000	1.59		
50,000	1.68		
60,000	1.73		
70,000	1.77		
80,000	1.81		
100,000	1.82		
140,000	1.85		
200,000	1.88		



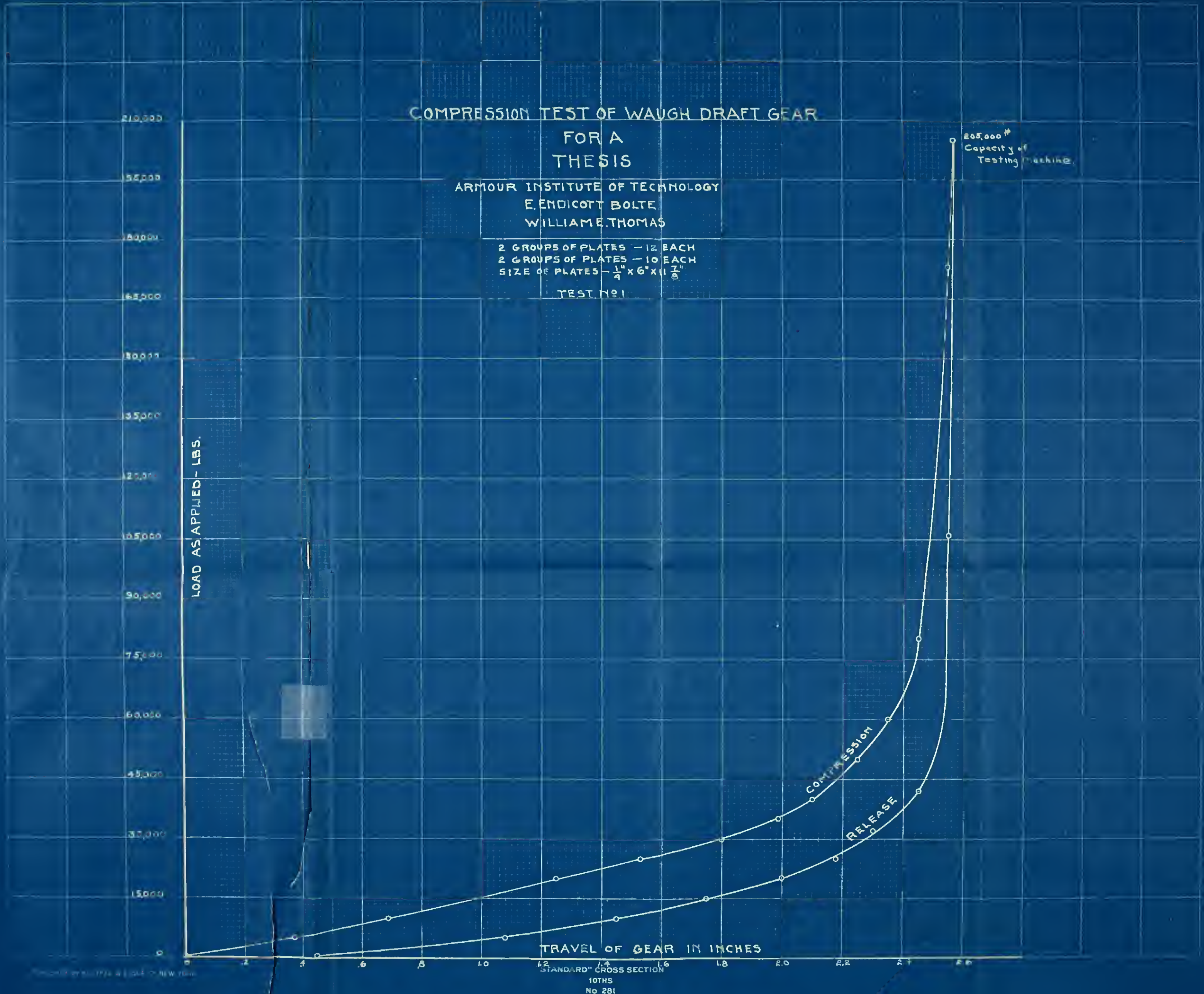
TEST Nº 5

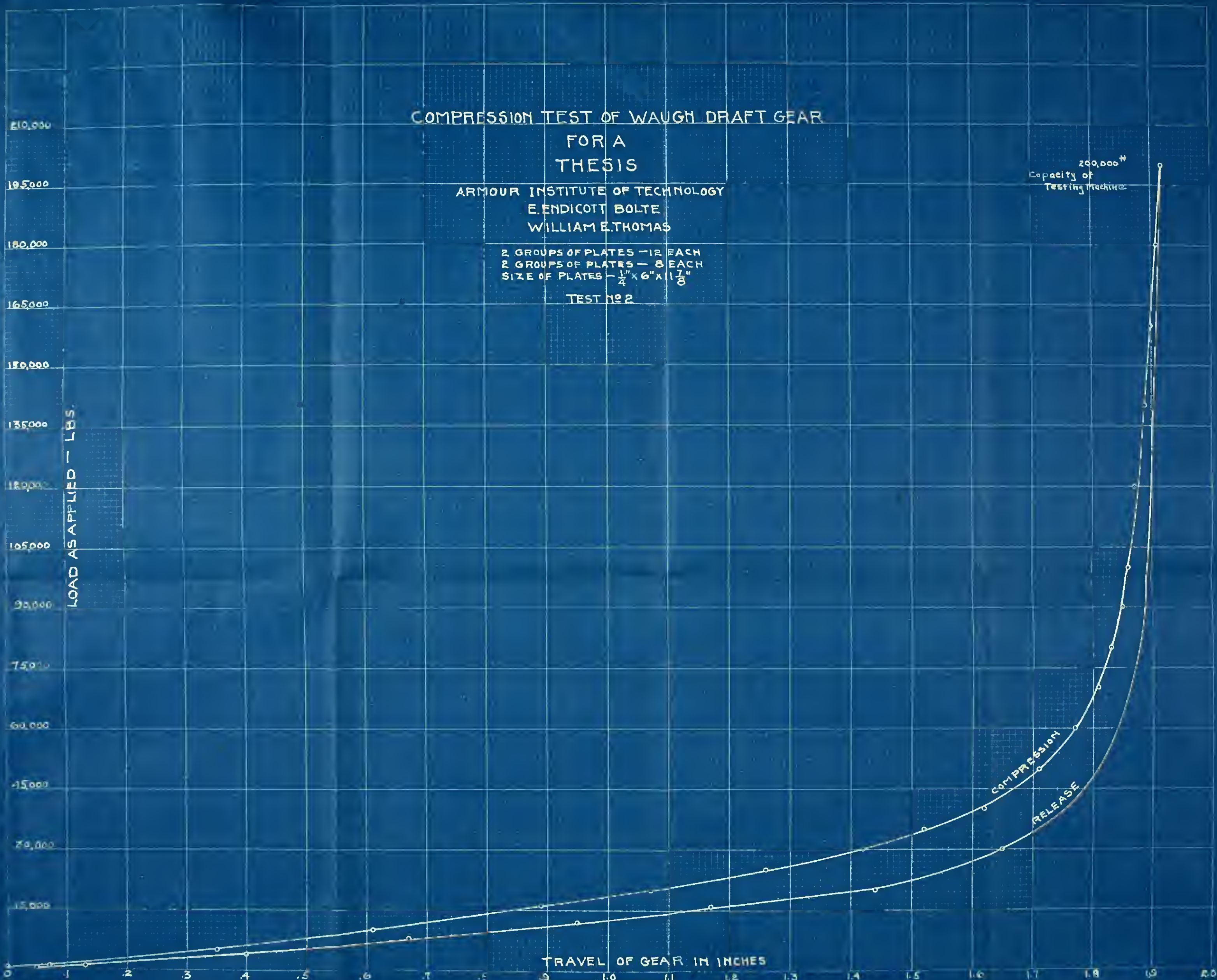
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
5,000 #	0.00 "	180,000 #	1.52 "
10,000	0.27	140,000	1.50
15,000	0.50	100,000	1.47
20,000	0.72	60,000	1.44
25,000	0.92	30,000	1.30
30,000	1.05	25,000	1.19
35,000	1.17	20,000	1.01
40,000	1.25	15,000	0.77
50,000	1.33	10,000	0.46
60,000	1.38	5,000	0.10
70,000	1.42	3,300	0.00
80,000	1.45		
90,000	1.46		
100,000	1.47		
120,000	1.48		
140,000	1.49		
160,000	1.50		
180,000	1.52		
200,000	1.53		



TEST № 6

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
5,000 #	0.00 "	30,000 #	1.30 "
10,000	0.27	20,000	1.01
15,000	0.50	15,000	0.78
20,000	0.73	10,000	0.45
25,000	0.93	5,000	0.11
30,000	1.05		
35,000	1.16		
40,000	1.25		
50,000	1.34		
60,000	1.40		
70,000	1.43		
80,000	1.46		
90,000	1.47		
100,000	1.48		
120,000	1.49		
140,000	1.50		
160,000	1.52		
180,000	1.53		
200,000	1.55		





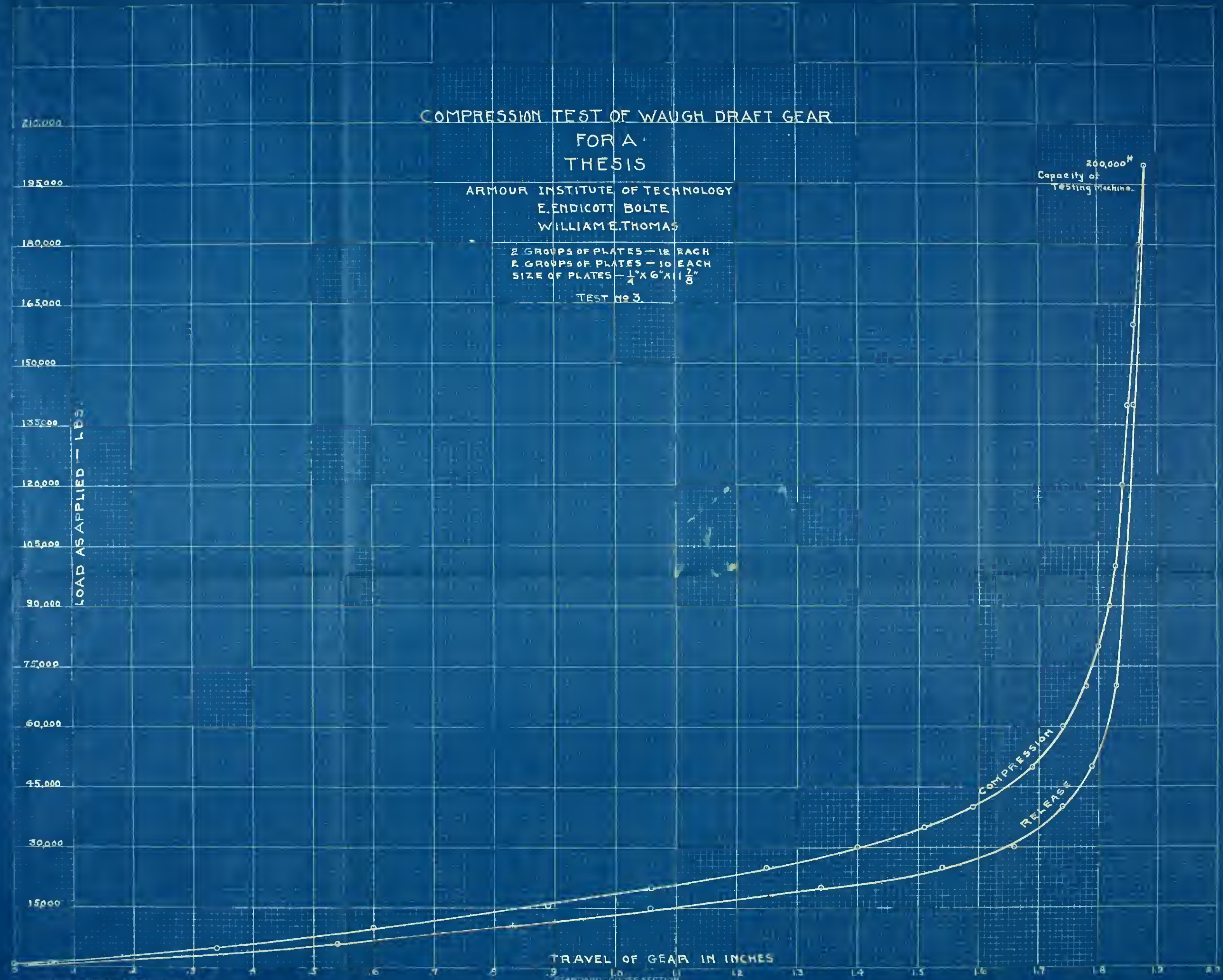
COMPRESSION TEST OF WAUGH DRAFT GEAR FOR A THESIS

ARMOUR INSTITUTE OF TECHNOLOGY
E. ENDICOTT BOLTE
WILLIAM E. THOMAS

2 GROUPS OF PLATES — 12 EACH
2 GROUPS OF PLATES — 8 EACH
SIZE OF PLATES — $\frac{1}{4}$" × 6" × 11$\frac{7}{8}$"

TEST No. 2

KEUFFEL & ESSER Co NEW YORK
"STANDARD" CROSS SECTION
10THS
No. 281

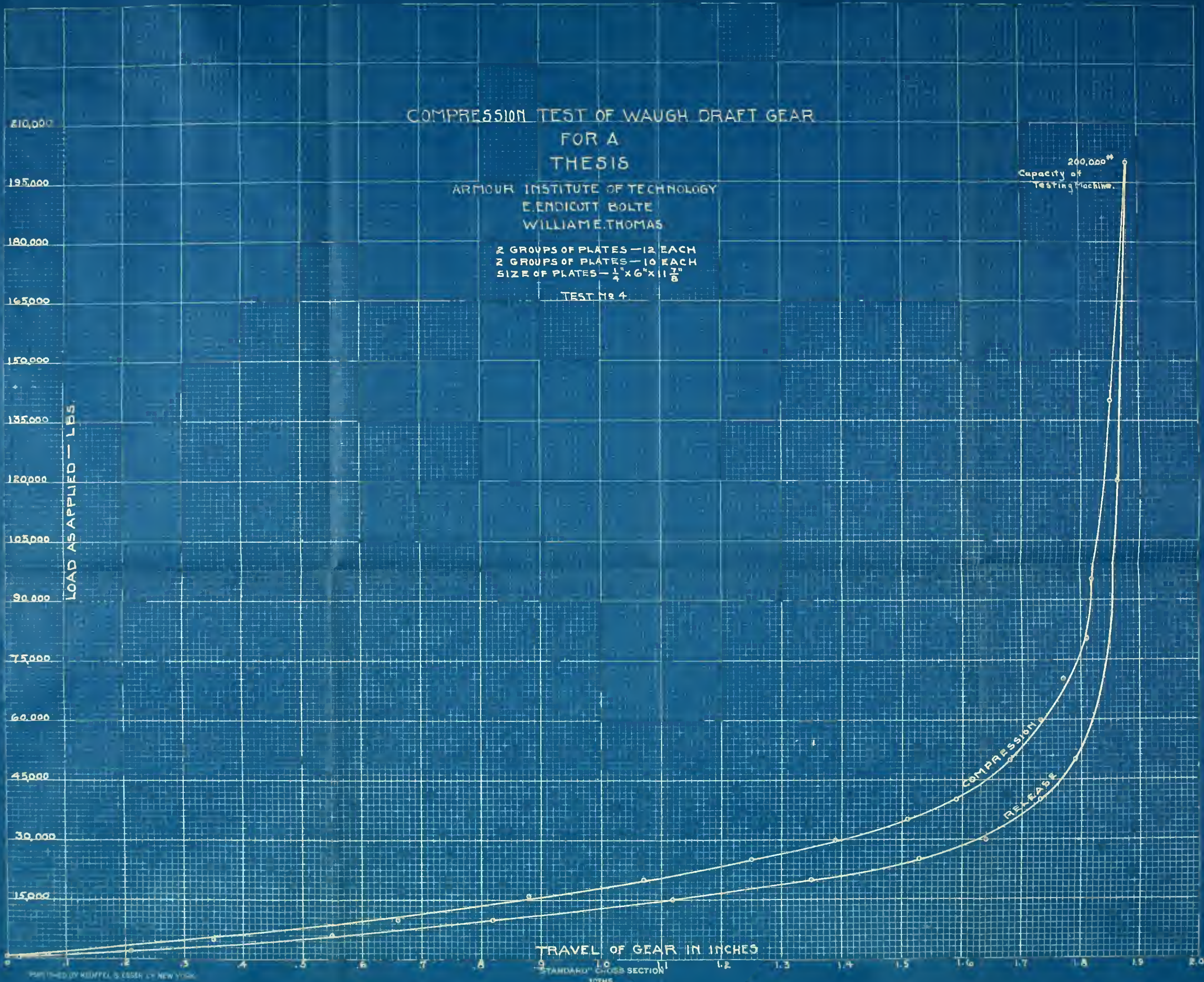


COMPRESSION TEST OF WAUGH DRAFT GEAR
FOR A
THESIS

ARMOUR INSTITUTE OF TECHNOLOGY
E. ENDICOTT BOLTE
WILLIAM E. THOMAS

2 GROUPS OF PLATES — 12 EACH
2 GROUPS OF PLATES — 10 EACH
SIZE OF PLATES — $\frac{1}{4}$" x 6" x 11 $\frac{7}{8}$"

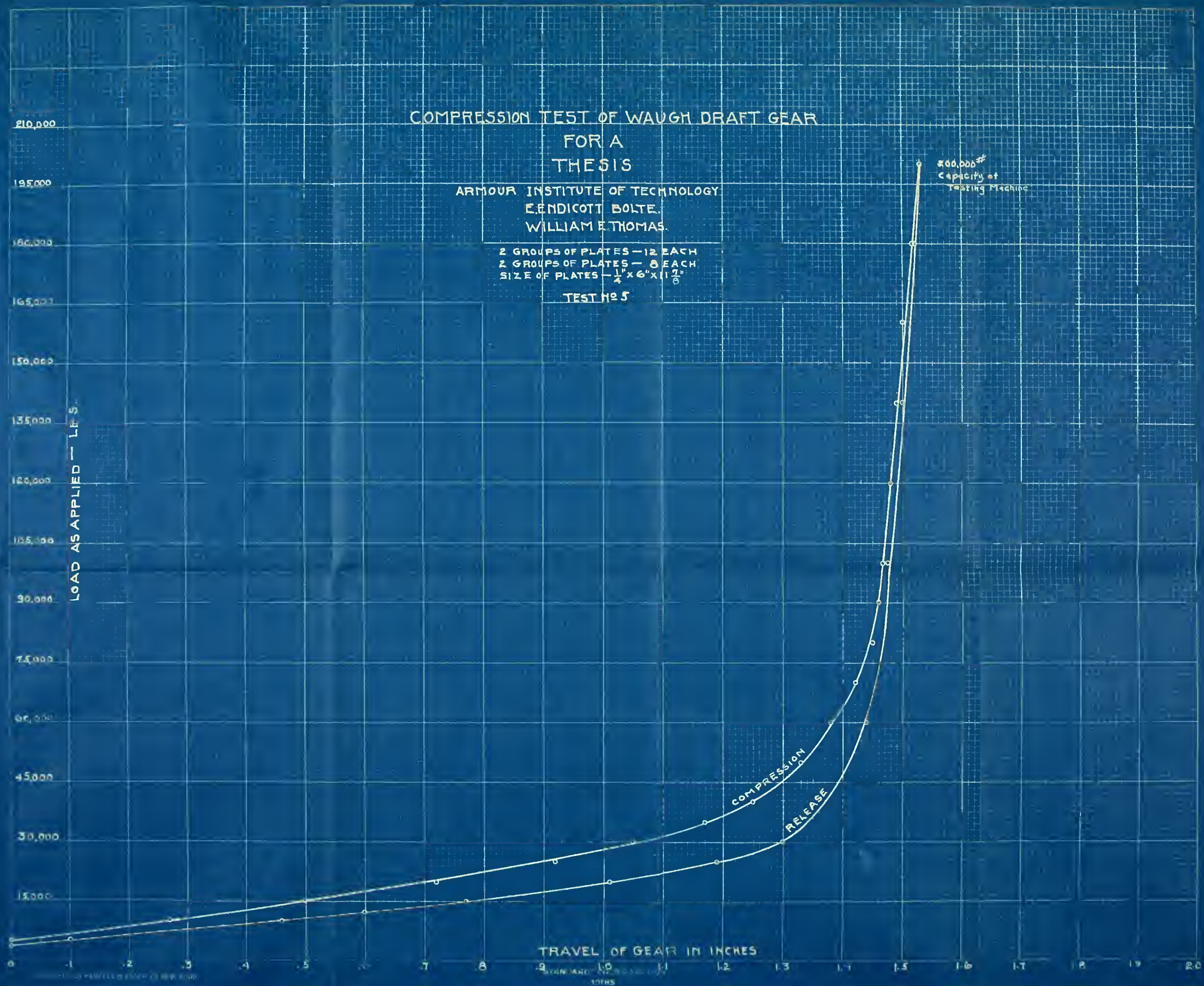
TEST No 3.


COMPRESSION TEST OF WAUGH DRAFT GEAR
FOR A
THESIS
ARMOUR INSTITUTE OF TECHNOLOGY
E. ENDICOTT BOLTE
WILLIAM E. THOMAS

2 GROUPS OF PLATES — 12 EACH
2 GROUPS OF PLATES — 10 EACH
SIZE OF PLATES — $\frac{1}{4}$" x 6" x 11 $\frac{7}{8}$"

TEST No 4

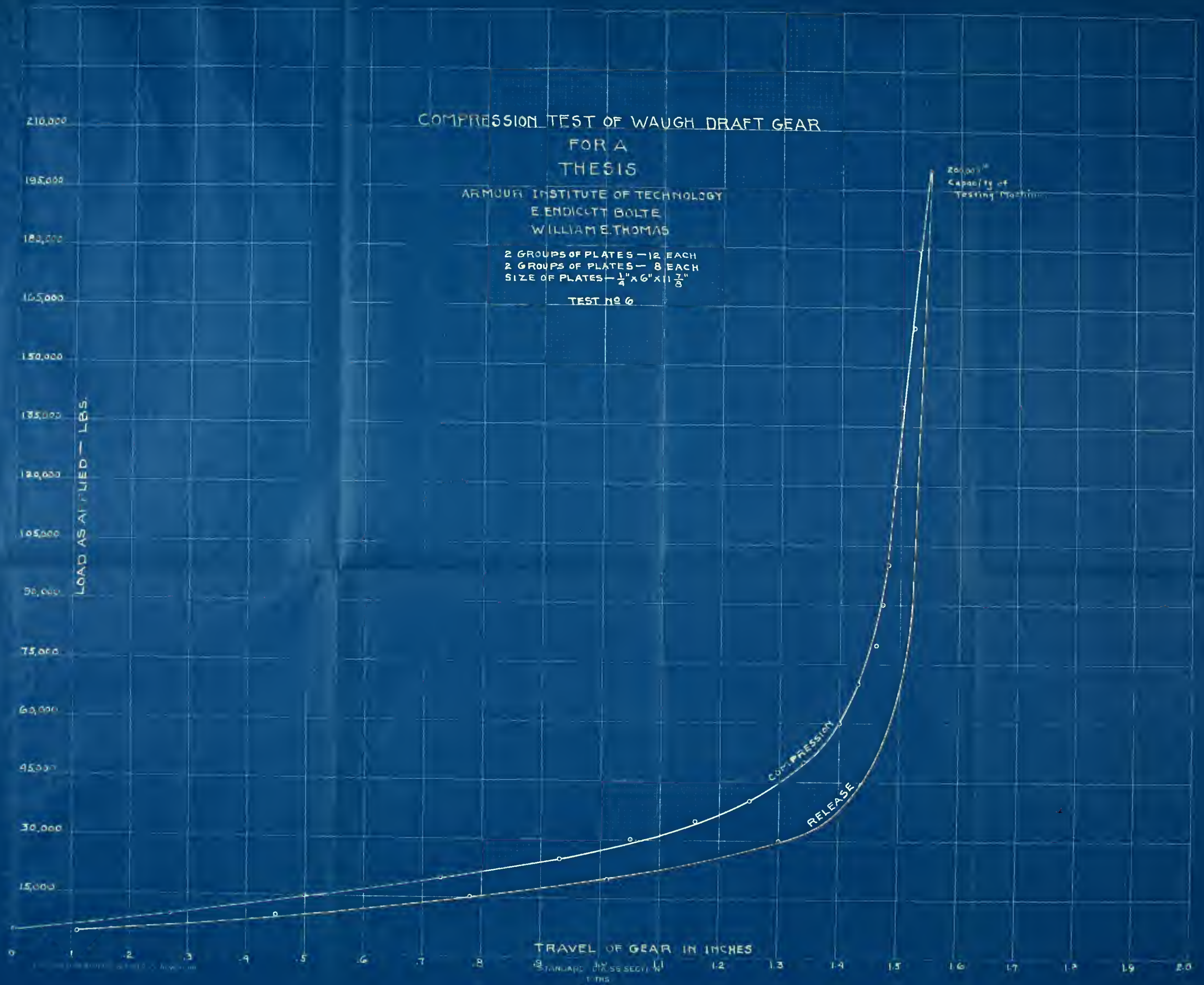
PUBLISHED BY KEUFFEL & ESSER Co. NEW YORK
"STANDARD" CROSS SECTION
10THS
No. 281



COMPRESSION TEST OF WAUGH DRAFT GEAR
FOR A
THESIS
ARMOUR INSTITUTE OF TECHNOLOGY
E. ENDICOTT BOLTE.
WILLIAM E. THOMAS.

2 GROUPS OF PLATES — 12 EACH
2 GROUPS OF PLATES — 8 EACH
SIZE OF PLATES — $\frac{1}{4}$" x 6" x 11 $\frac{7}{8}$"

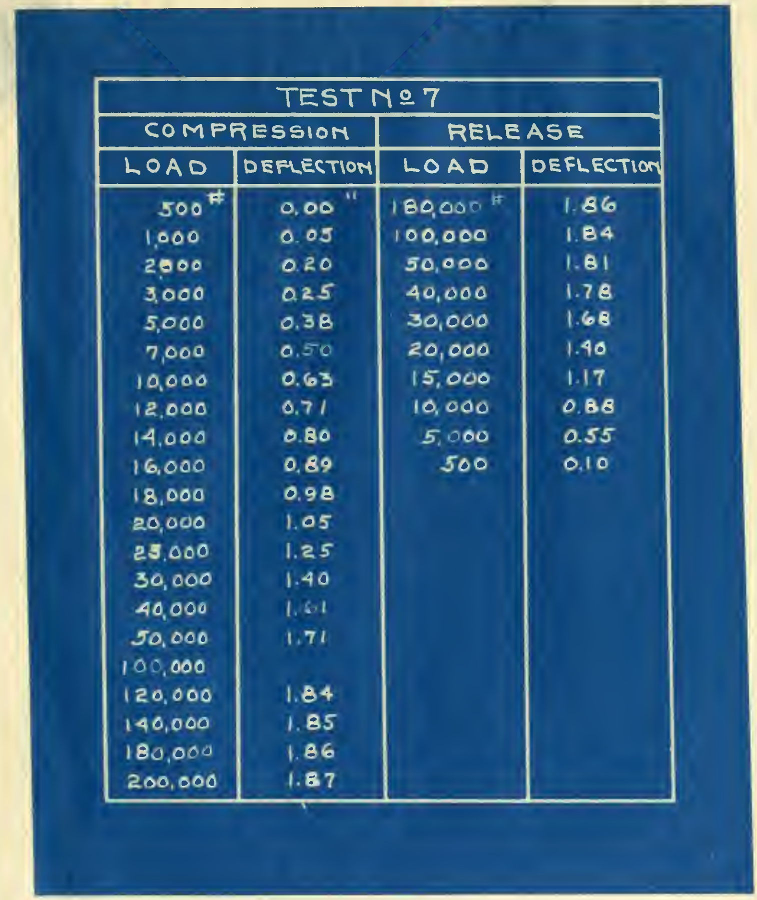
TEST No 5


COMPRESSION TEST OF WAUGH DRAFT GEAR
FOR A
THESIS

ARMOUR INSTITUTE OF TECHNOLOGY
E. ENDICOTT BOLTE
WILLIAM E. THOMAS

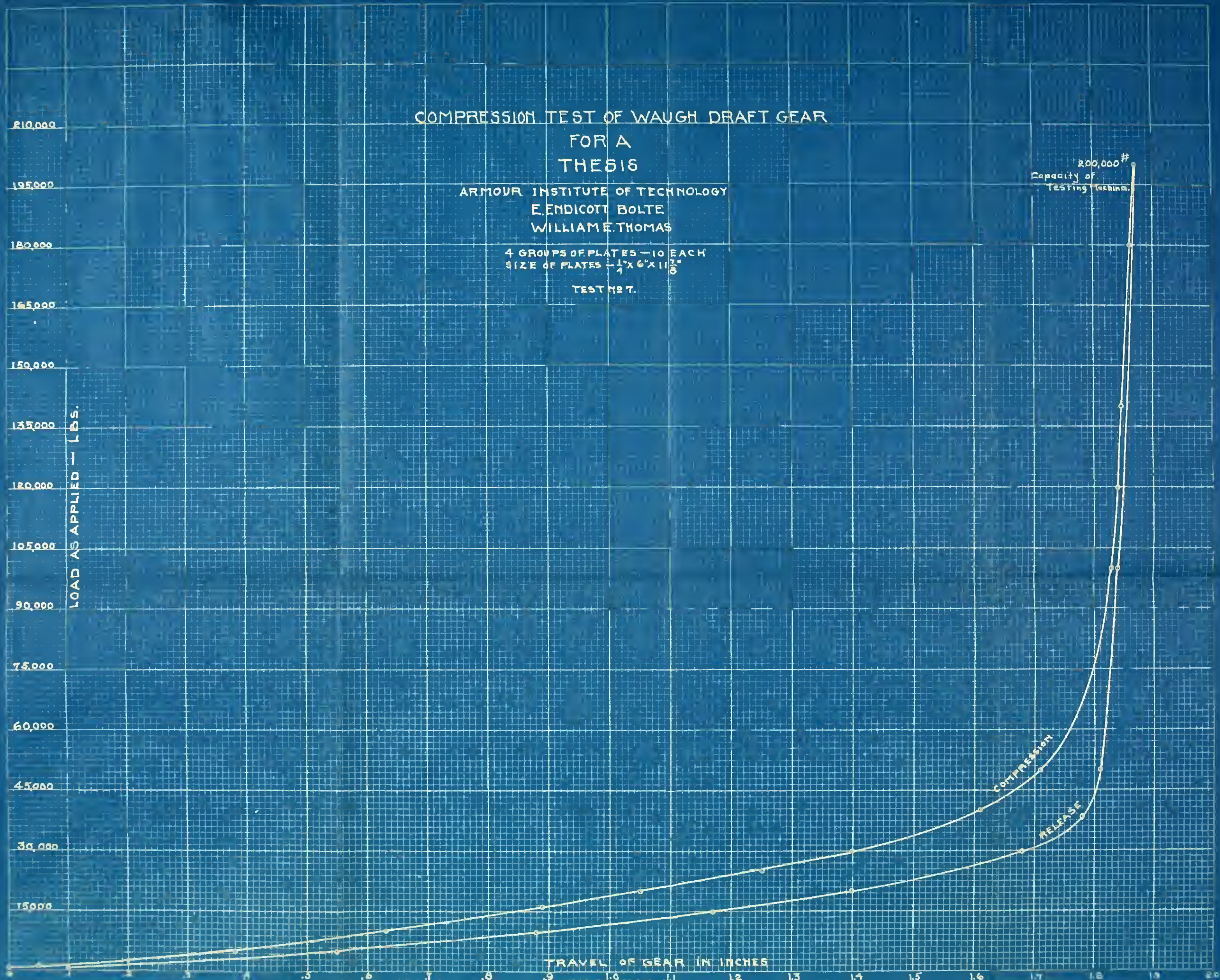
2 GROUPS OF PLATES — 12 EACH
2 GROUPS OF PLATES — 8 EACH
SIZE OF PLATES — $\frac{1}{4}$" x 6" x 11 $\frac{7}{8}$"

TEST No 6



TEST № 7

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500 #	0.00 "	180,000 #	1.86
1,000	0.05	100,000	1.84
2,000	0.20	50,000	1.81
3,000	0.25	40,000	1.78
5,000	0.38	30,000	1.68
7,000	0.50	20,000	1.40
10,000	0.63	15,000	1.17
12,000	0.71	10,000	0.88
14,000	0.80	5,000	0.55
16,000	0.89	500	0.10
18,000	0.98		
20,000	1.05		
25,000	1.25		
30,000	1.40		
40,000	1.61		
50,000	1.71		
100,000			
120,000	1.84		
140,000	1.85		
180,000	1.86		
200,000	1.87		

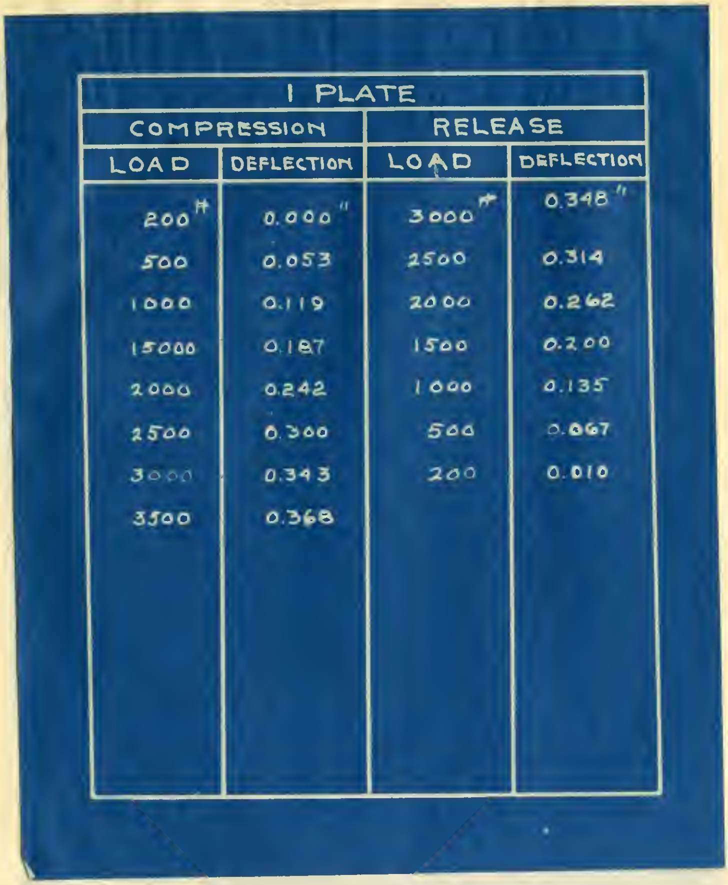


COMPRESSION TEST OF WAUGH DRAFT GEAR
FOR A
THESIS
ARMOUR INSTITUTE OF TECHNOLOGY
E. ENDICOTT BOLTE
WILLIAM E. THOMAS

4 GROUPS OF PLATES — 10 EACH
SIZE OF PLATES — $\frac{1}{4}$" X 6" X 11$\frac{7}{8}$"

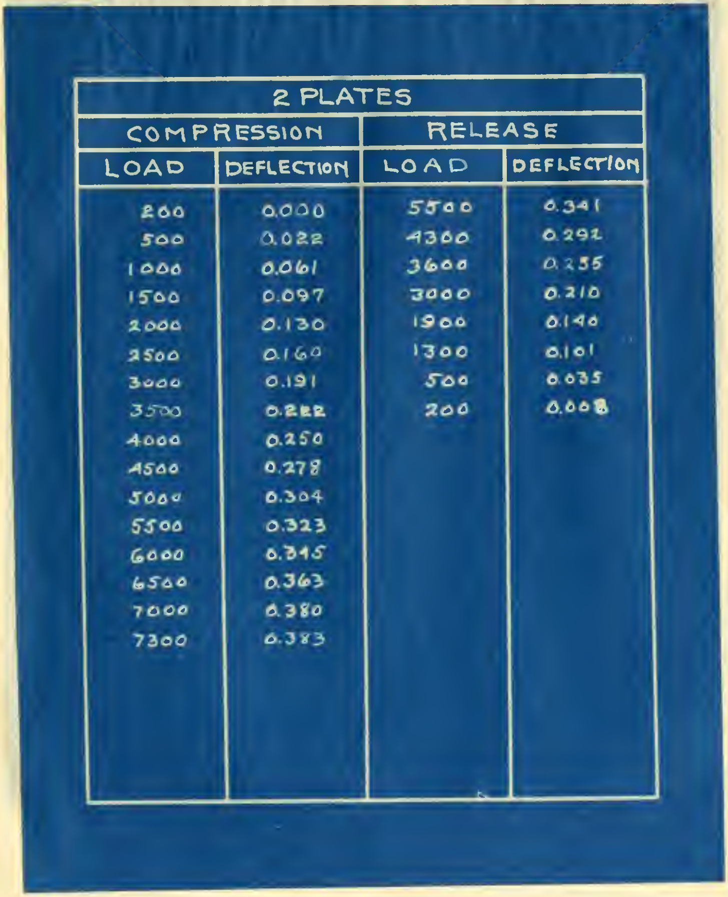
TEST No 7.

PUBLISHED BY KEUFFEL & ESSER CO. NEW YORK
"STANDARD" CROSS SECTION
10THS
No. 281



I PLATE

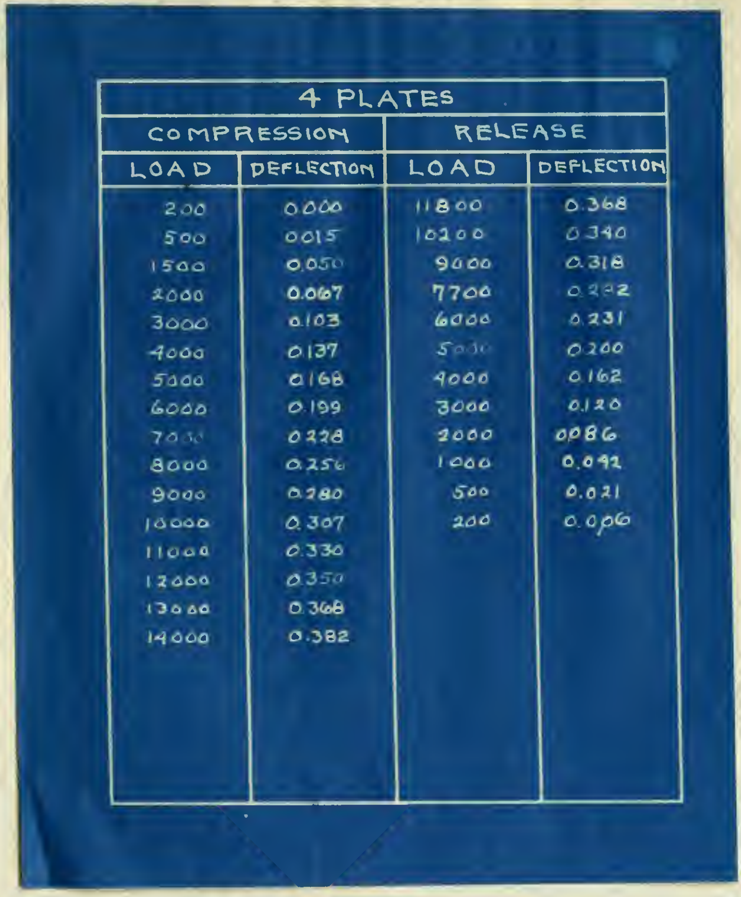
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200#	0.000"	3000#	0.348"
500	0.053	2500	0.314
1000	0.119	2000	0.262
15000	0.187	1500	0.200
2000	0.242	1000	0.135
2500	0.300	500	0.067
3000	0.343	200	0.010
3500	0.368		



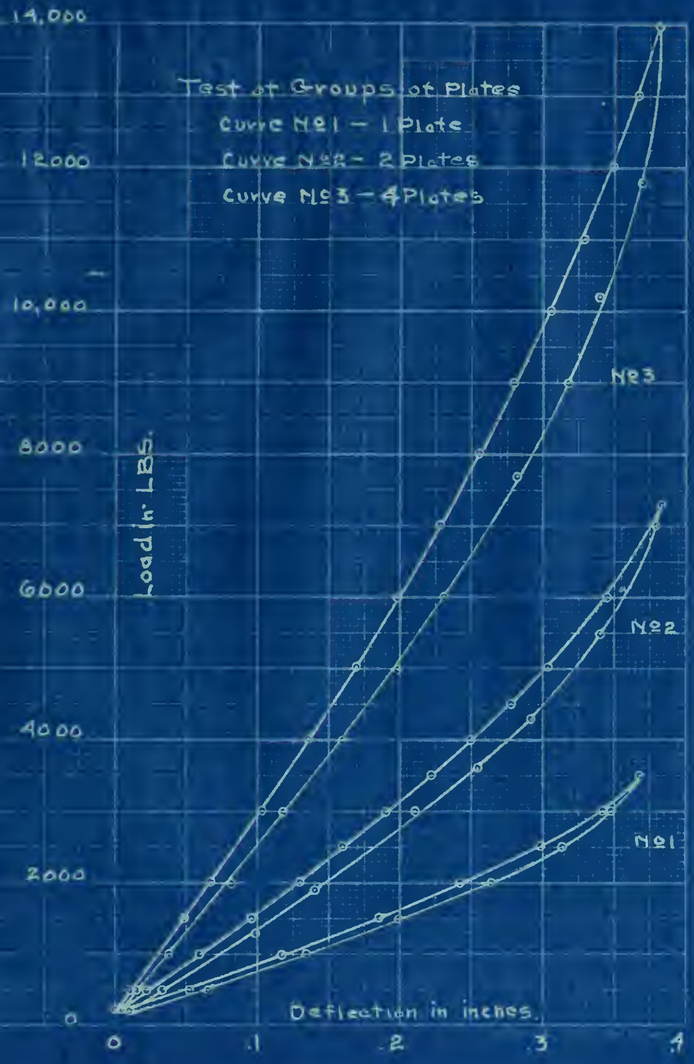
2 PLATES			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200	0.000	5500	0.341
500	0.022	4300	0.292
1000	0.061	3600	0.255
1500	0.097	3000	0.210
2000	0.130	1900	0.140
2500	0.160	1300	0.101
3000	0.191	500	0.035
3500	0.222	200	0.008
4000	0.250		
4500	0.278		
5000	0.304		
5500	0.323		
6000	0.345		
6500	0.363		
7000	0.380		
7300	0.383		

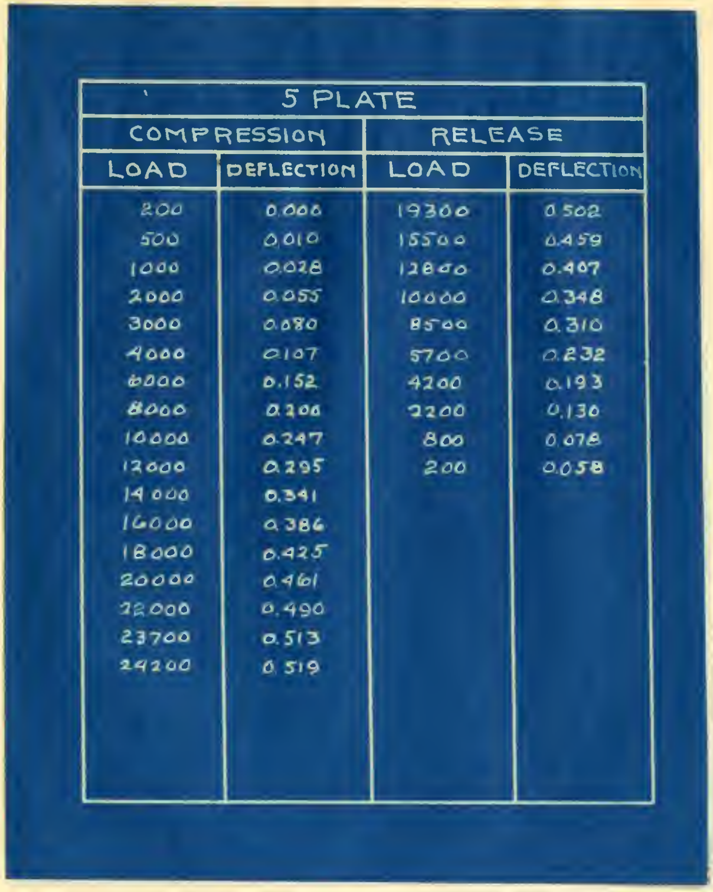
3 PLATES

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200	0.000	8700	0.360
500	0.018	7200	0.322
1000	0.040	6300	0.295
2000	0.088	5000	0.230
3000	0.134	4000	0.195
4000	0.176	2800	0.145
5000	0.258	2400	0.120
6000	0.292	1200	0.060
7200	0.322	600	0.028
9200	0.359	200	0.005
10200	0.380		



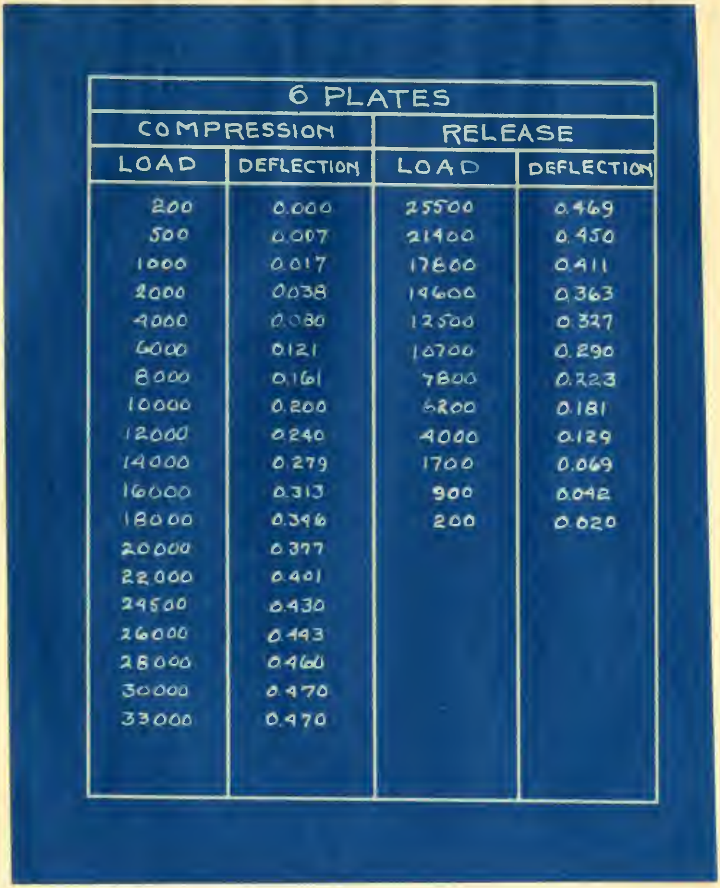
4 PLATES			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200	0.000	11800	0.368
500	0015	10200	0.340
1500	0.050	9000	0.318
2000	0.067	7700	0.282
3000	0.103	6000	0.231
4000	0.137	5000	0.200
5000	0.168	4000	0.162
6000	0.199	3000	0.120
7000	0.228	2000	0.086
8000	0.256	1000	0.042
9000	0.280	500	0.021
10000	0.307	200	0.006
11000	0.330		
12000	0.350		
13000	0.368		
14000	0.382		


Test of Groups of Plates
Curve Nº1 – 1 Plate
Curve Nº2 – 2 Plates
Curve Nº3 – 4 Plates
14,000
12000
10,000
8000
6000
4000
2000
0
Load in LBS.
Nº3
Nº2
Nº1
Deflection in inches.
0
.1
.2
.3
.4

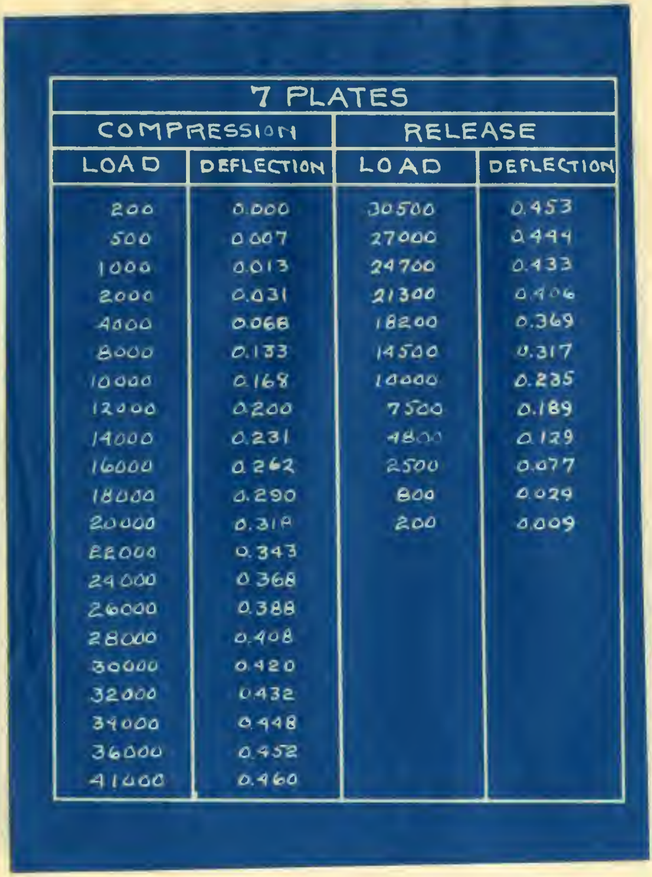


5 PLATE

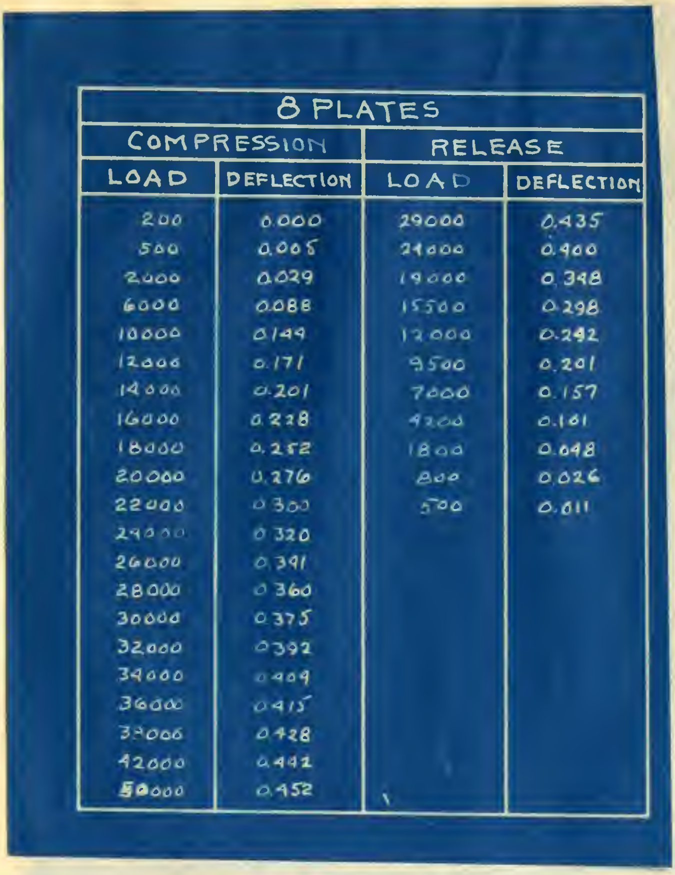
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200	0.000	19300	0.502
500	0.010	15500	0.459
1000	0.028	12800	0.407
2000	0.055	10000	0.348
3000	0.080	8500	0.310
4000	0.107	5700	0.232
6000	0.152	4200	0.193
8000	0.200	2200	0.130
10000	0.247	800	0.078
12000	0.295	200	0.058
14000	0.341		
16000	0.386		
18000	0.425		
20000	0.461		
22000	0.490		
23700	0.513		
24200	0.519		



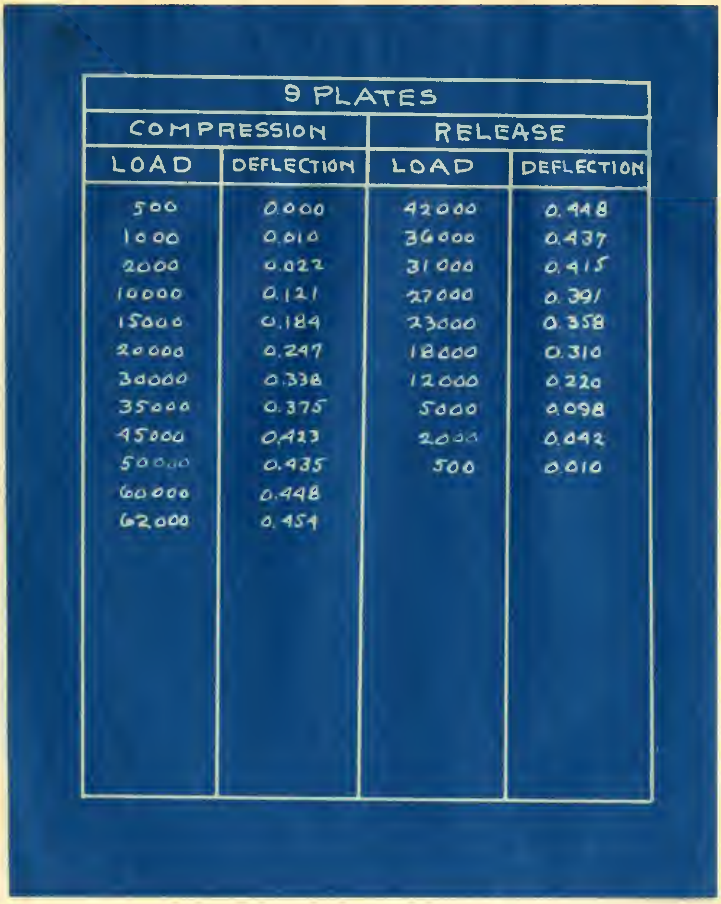
6 PLATES			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200	0.000	25500	0.469
500	0.007	21400	0.450
1000	0.017	17800	0.411
2000	0.038	14600	0.363
4000	0.080	12500	0.327
6000	0.121	10700	0.290
8000	0.161	7800	0.223
10000	0.200	6200	0.181
12000	0.240	4000	0.129
14000	0.279	1700	0.069
16000	0.313	900	0.042
18000	0.346	200	0.020
20000	0.377		
22000	0.401		
24500	0.430		
26000	0.443		
28000	0.460		
30000	0.470		
33000	0.470		



7 PLATES			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200	0.000	30500	0.453
500	0.007	27000	0.444
1000	0.013	24700	0.433
2000	0.031	21300	0.406
4000	0.068	18200	0.369
8000	0.133	14500	0.317
10000	0.168	10000	0.235
12000	0.200	7500	0.189
14000	0.231	4800	0.129
16000	0.262	2500	0.077
18000	0.290	800	0.029
20000	0.318	200	0.009
22000	0.343		
24000	0.368		
26000	0.388		
28000	0.408		
30000	0.420		
32000	0.432		
34000	0.448		
36000	0.452		
41000	0.460		



8 PLATES			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
200	0.000	29000	0.435
500	0.005	24000	0.400
2000	0.029	19000	0.348
6000	0.088	15500	0.298
10000	0.149	12000	0.242
12000	0.171	9500	0.201
14000	0.201	7000	0.157
16000	0.228	4200	0.101
18000	0.252	1800	0.048
20000	0.276	800	0.026
22000	0.300	500	0.011
24000	0.320		
26000	0.391		
28000	0.360		
30000	0.375		
32000	0.392		
34000	0.409		
36000	0.415		
38000	0.428		
42000	0.442		
50000	0.452		

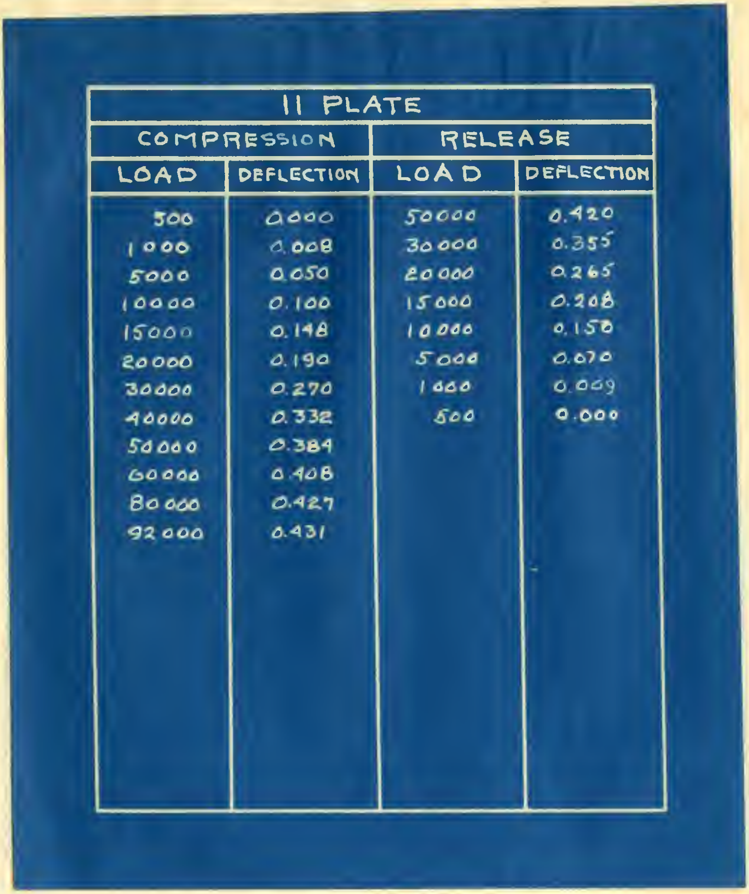


9 PLATES

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500	0.000	42000	0.448
1000	0.010	36000	0.437
2000	0.022	31000	0.415
10000	0.121	27000	0.391
15000	0.184	23000	0.358
20000	0.247	18000	0.310
30000	0.338	12000	0.220
35000	0.375	5000	0.098
45000	0.423	2000	0.042
50000	0.435	500	0.010
60000	0.448		
62000	0.454		

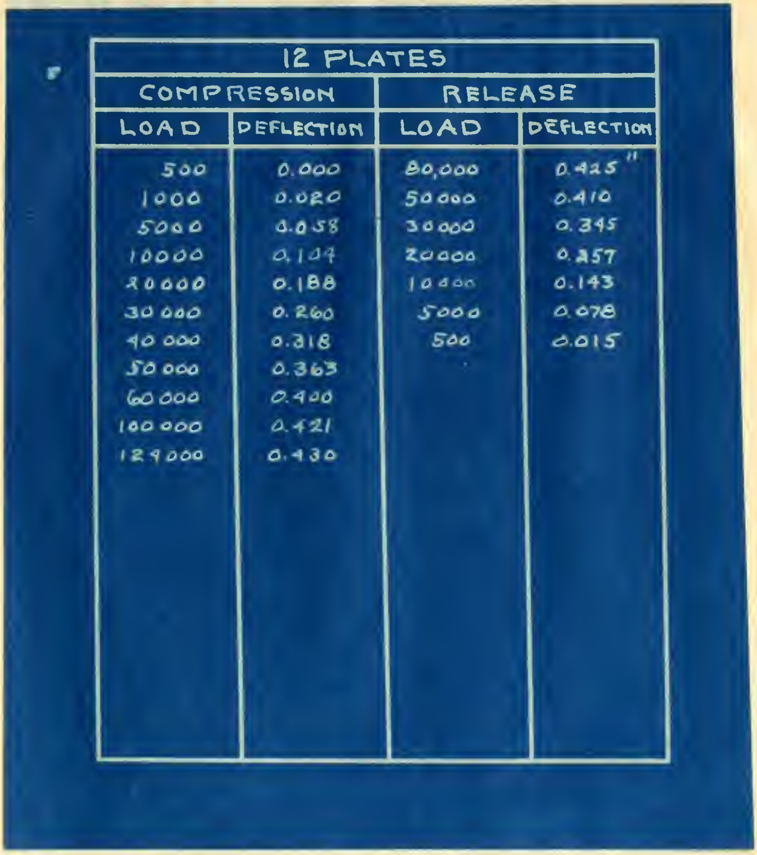
10 PLATES

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500	0.000	50000	0.430
1000	0.009	30000	0.378
5000	0.055	20000	0.290
10000	0.108	15000	0.230
15000	0.162	10000	0.162
20000	0.218	5000	0.082
25000	0.261	2000	0.031
30000	0.300	500	0.004
35000	0.342		
40000	0.370		
50000	0.410		
60000	0.428		
62000	0.435		
75000	0.441		

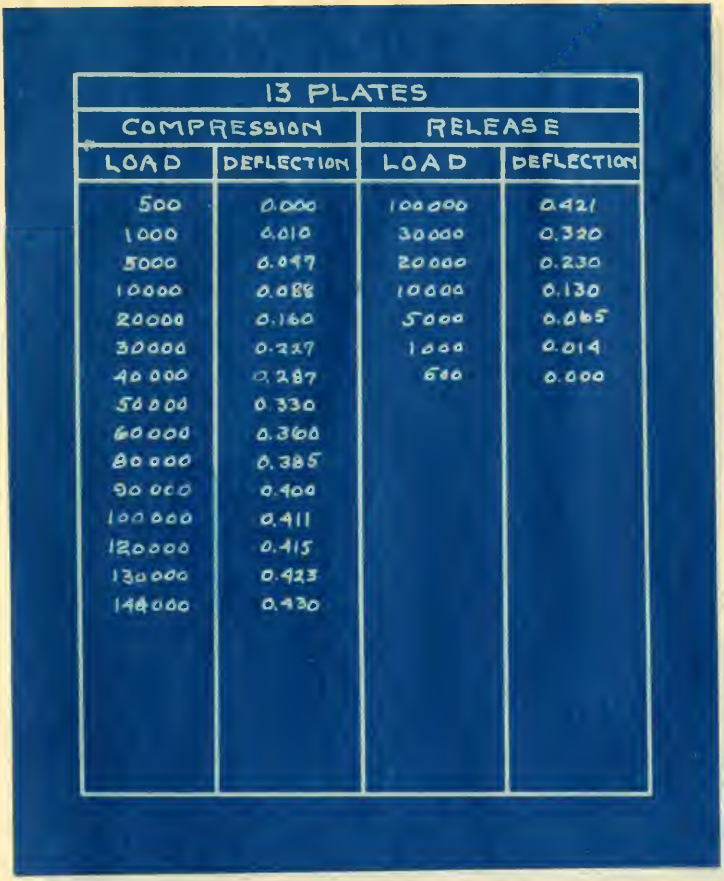


11 PLATE

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500	0.000	50000	0.420
1000	0.008	30 000	0.355
5000	0.050	20 000	0.265
10000	0.100	15 000	0.208
15000	0.148	10 000	0.150
20000	0.190	5 000	0.070
30000	0.270	1 000	0.009
40000	0.332	500	0.000
50000	0.384		
60000	0.408		
80 000	0.427		
92 000	0.431		



12 PLATES			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500	0.000	80,000	0.425"
1000	0.020	50000	0.410
5000	0.058	30000	0.345
10000	0.147	20000	0.257
20000	0.188	10000	0.143
30 000	0.260	5000	0.078
40 000	0.318	500	0.015
50 000	0.363		
60 000	0.400		
100 000	0.421		
129000	0.430		



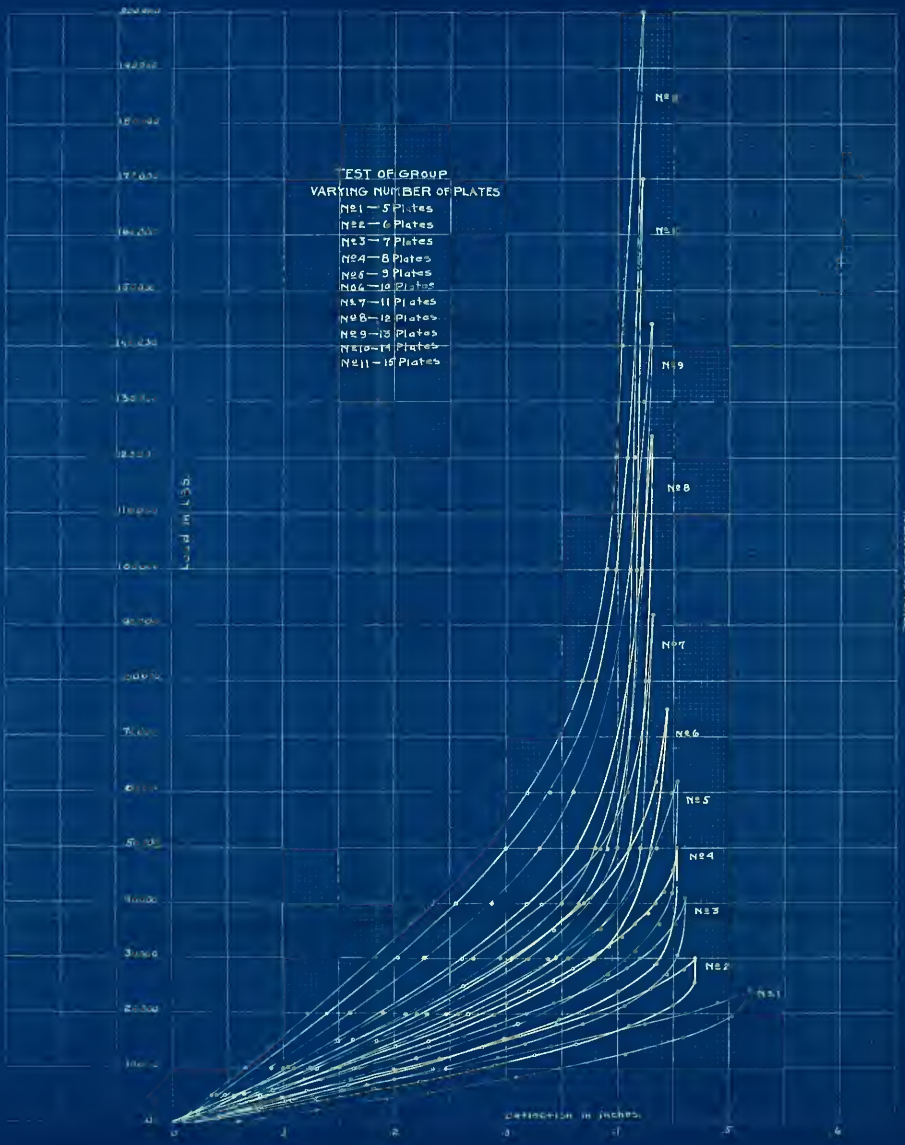
13 PLATES

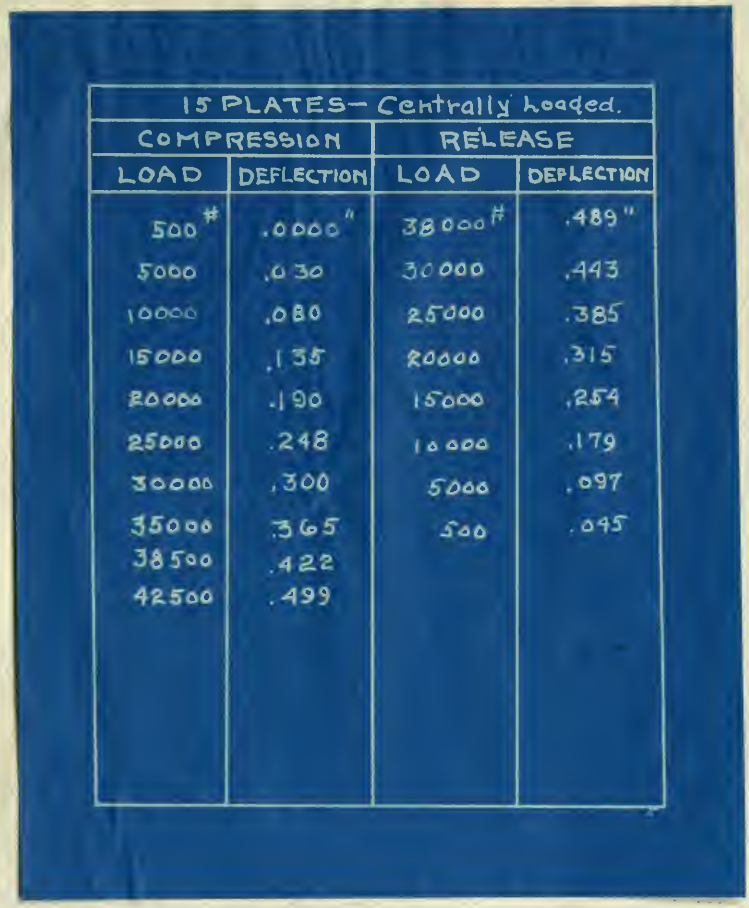
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500	0.000	100 000	0.421
1000	0.010	30000	0.320
5000	0.047	20000	0.230
10000	0.088	10000	0.130
20000	0.160	5000	0.065
30000	0.227	1000	0.014
40 000	0.287	600	0.000
50 000	0.330		
60 000	0.360		
80 000	0.385		
90 000	0.400		
100 000	0.411		
120000	0.415		
130 000	0.423		
144000	0.430		

14 PLATES

COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500	0.000	100000	0.0417
1000	0.010	50000	0.390
5000	0.038	40000	0.365
10000	0.070	30 000	0.305
20000	0.140	20000	0.220
30000	0.203	10000	0.125
40000	0.255	50 00	0.058
50000	0.300	1000	0.012
60 000	0.340	500	0.004
80000	0.380		
100 000	0.398		
120 000	0.408		
140000	0.417		
170000	0.421		

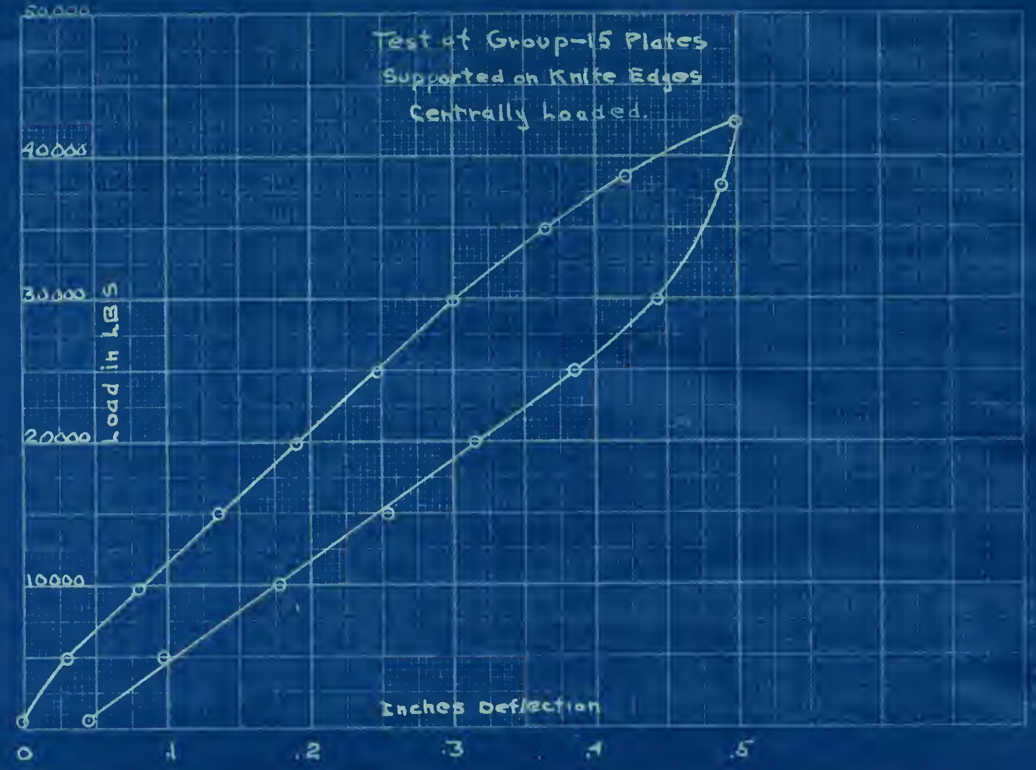
15 PLATES			
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500	0.000	150000	0.419
1 000	0.008	100 000	0.412
5000	0.035	50 000	0.380
10 000	0.067	40 000	0.350
20000	0.122	30 000	0.295
30000	0.183	20000	0.210
40000	0.234	10 000	0.110
60 000	0.318	5000	0.055
80 000	0.368	500	0.005
100 000	0.390		
120 000	0.398		
140 000	0.404		
160 000	0.410		
200000	0.422		

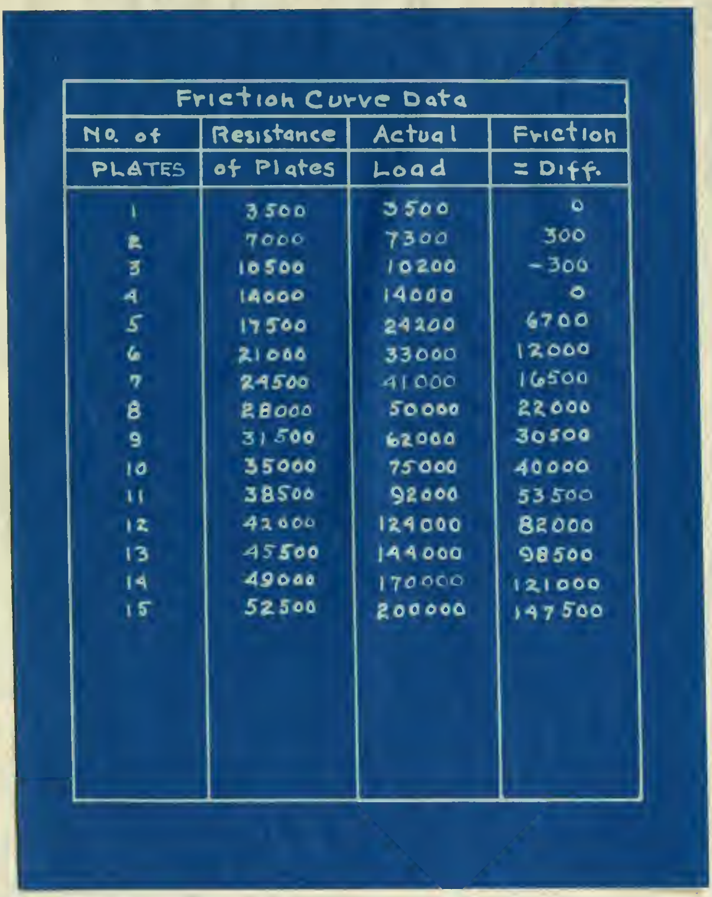

TEST OF GROUP
VARYING NUMBER OF PLATES
N°1 — 5 Plates
N°2 — 6 Plates
N°3 — 7 Plates
N°4 — 8 Plates
N°5 — 9 Plates
N°6 — 10 Plates
N°7 — 11 Plates
N°8 — 12 Plates
N°9 — 13 Plates
N°10 — 14 Plates
N°11 — 15 Plates
N°11
N°10
N°9
N°8
N°7
N°6
N°5
N°4
N°3
N°2
N°1
200000
190000
180000
170000
160000
150000
140000
130000
120000
110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Load in Lbs.
0
.1
.2
.3
.4
.5
.6
Deflection in Inches
STANDARD CROSS SECTION



15 PLATES— Centrally Loaded.

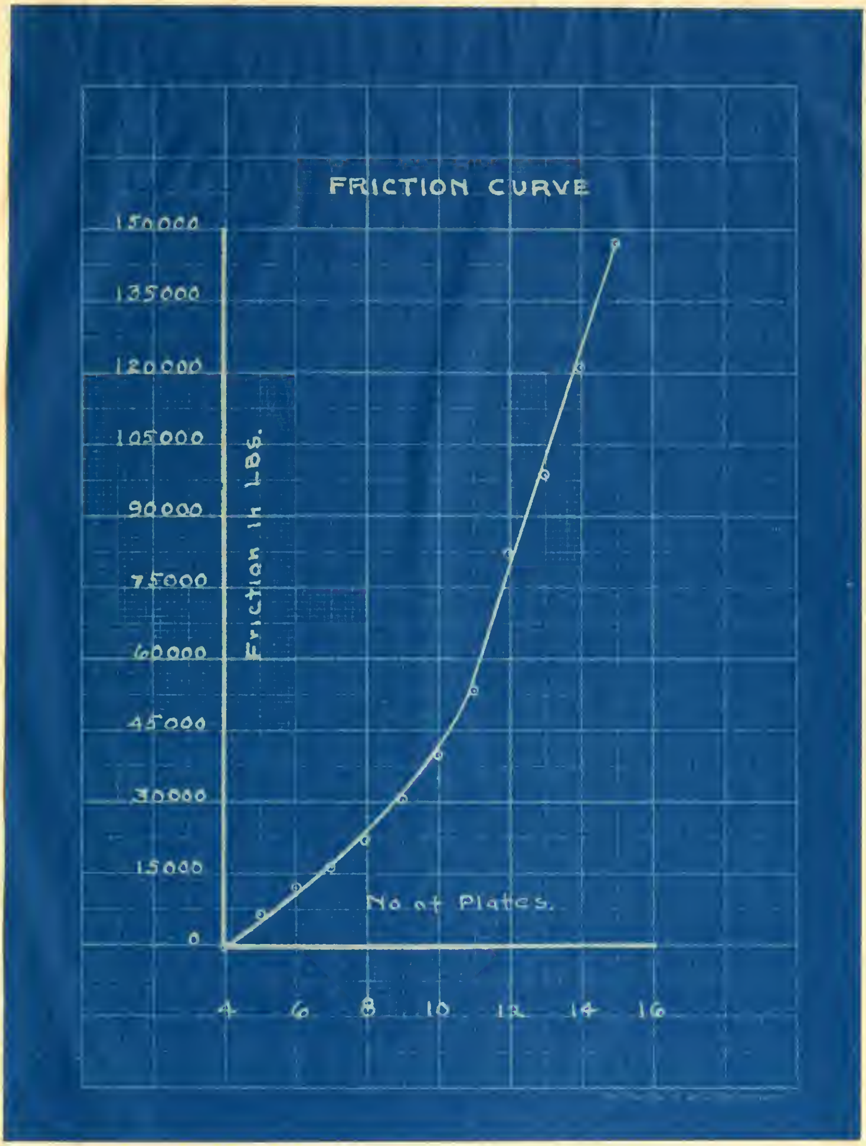
COMPRESSION		RELEASE	
LOAD	DEFLECTION	LOAD	DEFLECTION
500#	.0000"	38000#	.489"
5000	.030	30000	.443
10000	.080	25000	.385
15000	.135	20000	.315
20000	.190	15000	.254
25000	.248	10000	.179
30000	.300	5000	.097
35000	.365	500	.045
38500	.422		
42500	.499		


Test of Group-15 Plates
Supported on Knife Edges
Centrally Loaded.



Friction Curve Data

No. of PLATES	Resistance of Plates	Actual Load	Friction = Diff.
1	3500	3500	0
2	7000	7300	300
3	10500	10200	-300
4	14000	14000	0
5	17500	24200	6700
6	21000	33000	12000
7	24500	41000	16500
8	28000	50000	22000
9	31500	62000	30500
10	35000	75000	40000
11	38500	92000	53500
12	42000	124000	82000
13	45500	144000	98500
14	49000	170000	121000
15	52500	200000	147500



FRICTION CURVE